The viability and public perception of the introduction of bio-hydrogen technology to Wales with specific reference to anaerobic dark fermentation of agricultural crops

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Table of Contents

Appendix 1 – An exploratory study of public opinions on the use of hydrogen energy in Wales

Appendix 2 – The potential of hydrogen – enriched biogas production from crops: Scenarios in the UK

Appendix 3 – Social grade definition

Appendix 4 - Derivation of net energy equation

Appendix 5 – Report submitted by PSP

Appendix 6 – Office of Science and Technology briefing notes on the hydrogen economy

Appendix 7 – Topics to cover

Appendix 8 – Photographs used in second session

Appendix 9 - Questionnaire

List of Figures

List of Tables

Abstract

Hydrogen technology has widely been acknowledged as a route to reduced carbon emissions and energy security. However, it is also recognised that technology development alone is not enough to cause a shift change in uptake and that public perception also needs to be considered. This paper identifies the public perception of hydrogen technology (with specific interest in biologically produced hydrogen) and determines whether it meets the public expectation in terms of its potential energetic output. The energetic viability of hydrogen (defined for this purpose as a net positive energy balance) is derived by determining the potential for agriculturally produced hydrogen using dark fermentative production techniques. A suitable range of energy crops have been identified using selection criteria including yield, harvest window and composition of the crops. Public perception of hydrogen energy was investigated through the use of two focus groups. This identified Welsh public opinions on the production and end use of hydrogen energy.

This was the first study to be undertaken to research hydrogen perception using qualitative research techniques in Wales and one of the first in the UK.

The public perception study identified gender differences, with women generally more accepting of hydrogen technology. The main concerns were safety (both of use and in production) and cost. Specific aspects of dark fermentation technology were able to address a number of the participants concerns relating to pollution being moved to production sites. The groups' attitude to the development of hydrogen technology was supportive but with the caveat that price and safety should not be compromised.

It must be noted that this was a small scale exploratory study and, therefore, the results are not statistically rigorous. This work has however been followed up by others in the field using qualitative techniques, and similar results have been repeated.

The second study performed under this MPhil study was the quantification of biohydrogen potential from crops available in the UK and undertaken as part of the

UK SHEC work package. This is the first time this has been calculated and this work was done in order to determine whether it is energetically feasible if performed at full-scale.

Fodder Beet, Perennial Rye Grass and Forage Maize have been identified as the most suitable energy crops and it would be feasible to produce 0.47 TWh of electrical energy annually. This would be enough to power circa 10% of welsh homes, based on the use of a conservative amount (8%) of welsh arable land.

This equates to a reduction in CO_2 emissions by over 114,768 tonnes per annum in the UK and would deliver 10% of the reduction target set for 2010.

The conclusion of this study is that it is energetically favourable to convert crops to hydrogen on a farm scale, provided that the correct crops and the most energetically favourable methods of farming and conversion are used. Taking into consideration the public perception study results, this approach would be favourable to the public and meet with their pre existing expectations that biologically produced hydrogen would be better for the environment than fossil fuel produced hydrogen and that decentralisation could be a positive outcome. Production of bio hydrogen from dark fermentation can be a net energy producing process and a valid and viable option for future pursuance and research.

For future studies, it is recommended that a different approach to candidate selection is adopted. This should seek a wider range of social grades, people from rural Wales and Welsh speakers in order to determine whether there are, within the Welsh demographic, cultural differences to the introduction of hydrogen technology. In addition, it is recommended that the cost effectiveness of the technology is investigated in order to find a tipping point whereby hydrogen production from crops becomes competitive with both food production and future fossil fuel pricing.

1. Introduction

This work* was carried out in conjunction with People Science and Policy as part of the H2Wales project and was published under the title 'An exploratory study of public opinions on the use of hydrogen energy in Wales' in the journal of Public Understanding of Science in 2008 (Appendix 1) and as part of the UK's Sustainable Hydrogen Energy Consortium (UK-SHEC) work packages†. Further aspects of this work were published under the title 'The potential for hydrogen-enriched biogas production from crops: Scenarios in the UK' in the journal of Biomass and Bioenergy in 2007 (Appendix 2).

1.1. Relevance of research work and outline of aims and objectives

Wales has, like many other European countries, pledged to reduce carbon dioxide emissions in order to try to abate climate change. It is also acutely aware of security of supply issues relating to fossil fuels, with a new LPG (Liquid Petroleum Gas) terminal being built in West Wales in order to import gas.

Although most of the population of circa 2 million (~66%) live in the larger cities and towns of the south Wales valleys and the coastal regions of south and north Wales, the remaining population is relatively sparsely distributed [1]. Some rural populations suffer with poor supply infrastructure with reliance on road transportation for coal and oil [2]. Access to energy is therefore paramount.

Through ratification of the Kyoto Protocol [3] the UK is committed to reducing CO_2 emissions by 12.5% below 1990 levels by 2010 [4] of which Wales is expected to produce 4 TWh per annum of renewable energy by 2010 and 7 TWh by 2020 [5].

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* This study was carried out as part of the H2 Wales study in 2003. The specified topics and data collection methods were planned by the author, with the work carried out under tender by People Science Policy Ltd (PSP). The author was in attendance and took part in one of the two sessions. A report presenting the data was provided by PSP and the results were then interpreted and conclusions drawn by the author as part of this MPhil study.

† The data collection and analysis work were performed by the author and Nuria Martinez Perez. The author collated a large proportion of the energy data and a small proportion of the crop data. The author then also developed the analytical calculations based on stoichiometry and adapted the data base in order to create the results. The author analysed the results and concluded on findings. The author also derived the energy conversion factors and resulting output.

In meeting the requirements of the Kyoto protocol, hydrogen has received much attention. Hydrogen fuel could have a zero carbon emission rating, if produced and distributed using renewable energy, including wind hydrogen, wave hydrogen or solar hydrogen.

The requirements of the Kyoto protocol do not rule out fossil fuel production but would need to be combined with a proven carbon capture and sequestration technology to reduce the overall CO_2 levels, this is also reliant on the availability and continued access to the raw materials. [6]

Wales has access to industrial sized fossil fuel hydrogen production methods for hydrogen distribution in and close to population centres [2]. Further small scale experimental projects produce renewable hydrogen from activities like the Renewable Hydrogen Research and Development Centre and research and pilot scale facilities producing hydrogen from organic wastes and energy crops from the University of Glamorgan [7].

The use of renewable energy sources to generate hydrogen is perceived to have additional benefits in that hydrogen acts as an energy storage vector, addressing the inherent "on demand" issues associated with the intermittent nature of renewable energy sources [6]. Further, use of hydrogen enables the storage of energy over long periods and enables energy transportation.

Experimental projects have assessed biomass gasification and dark fermentation as methods for hydrogen production, and these are suitable for use in rural areas. Woody biomass, with low water content, is suitable for use in gasification plants and wet biomass, with high carbohydrate content, waste from food industry and other waste streams could be converted to hydrogen via dark anaerobic fermentation processes [7,8]. The work undertaken as part of this study specifically focuses on the dark fermentation of crops in a Welsh climate.

The development of a hydrogen economy in Wales is reliant on a number of factors and includes;

- The raw materials, potential and know how to produce hydrogen;
- Availability (easily accessible) to hydrogen;
- Uptake of the technology.

This research will address some of these factors; the production and possible extent of raw materials (feedstock i.e. crops); the energy inputs required; and net energy outcomes; and the likely public opinion of a transition to hydrogen using an agricultural based system, which could affect the uptake of the technology. It is the intention to focus here on agricultural-based hydrogen production systems, in order to provide a rural hydrogen supply. Previous work has characterised the extent of existing production routes [8,9].

Production systems will be sited around arable land, as these systems can be distributed around rural Wales with minimal effort, and a number of farmers are already familiar with Anaerobic Digestion (AD) technologies, as they are used commonly in the agricultural sector to treat animal slurries.

Wales has nearly 2,000,000 ha dedicated to farming activities [10]. The carbon benefit of any renewable based technology is negated if it is required to be transported over large distances to reach the point of consumption. As such a home grown approach to hydrogen generation in the country is advocated.

In order to plan for the introduction of the hydrogen into the energy economy of Wales, the public perception of this technology needs to be investigated: historically public opinion has been a stumbling block to the introduction of new technologies [11]. If public opinion was not favourable to the technology, take-up would be slow and any benefit (in terms of carbon dioxide reduction and energy security) would take longer to be realised. It is important to understand public expectations of the technology and how these can be met and managed, alongside understanding their concerns over the introduction of this technology and how far these can be addressed [12]. It is vitally important that public perception of hydrogen is understood in terms of what factors are considered to be important (e.g. using clean energy production, cost) otherwise the technology may be boycotted or key benefits not being understood. There is also a need to understand how the public view of the end product, the vehicles or homes it may be used in or the safety of the technology.

In Summary: This paper aims to assess the public perception of hydrogen technology (with specific interest in biologically produced hydrogen) and to determine whether it meets the expectation of the public in terms of its energetic output. The viability is defined in terms of public perception (i.e. how acceptable it is to the public and is the proposed system energetically viable (defined for this purpose as a positive overall energy balance)).

1.2. Hydrogen production processes with the potential for rural application

1.2.1. Dark fermentation

Research into biologically generated hydrogen has gained momentum in the last decade [e.g. 13, 14, 15]. Reactor designs have primarily been based on methanogenic anaerobic digestion technologies used in waste and waste water treatment. These designs utilise dark fermentative processes (i.e. absence of light) in anaerobic conditions for hydrogen production.

Of these techniques, it was noted in two stage anaerobic digestion systems there were increased rates of substrate decomposition, higher methane yields and improved process stability compared to the equivalent single stage system [16]. An integrated and sustainable system for production of hydrogen and methane from biomass in a two stage system was proposed (Figure 1).

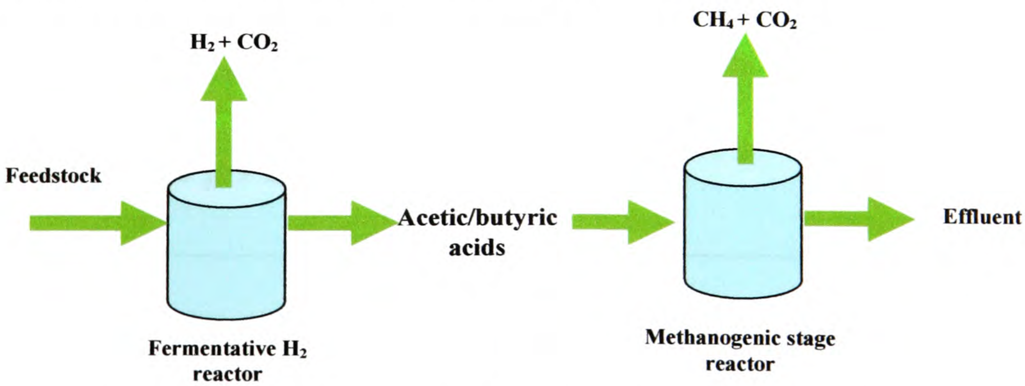

Figure 1 Two stage system for hydrogen and methane production from wet biomass.

For this system of hydrogen production the fermentative bacteria producing hydrogen may be selected either from a pure culture or from natural mixed culture. A natural source such as anaerobically digested sewage sludge or soil, would be preferable as it is likely to be uneconomic to ensure the required sterile conditions for a pure bacterial culture on a small to medium scale. Pure cultures of extreme thermophiles (requiring temperatures of 65°C or above) are not energetically feasible [17,18] unless there is high energy recovery.

For a mixed flora culture, working at optimal conditions, a carbohydrate rich organic material (e.g. root crops, fodder grass or food industry co-products) could, yield 4 moles hydrogen per mole of hexose sugar (e.g. glucose) fermented (see equation 1) equating to circa 0.5 m^3 hydrogen per kg glucose equivalent. Fermentation end products such as acetic and butyric acids, together with any undigested biomass, can then undergo methanogenic anaerobic digestion.

Where the feedstock is grown crops, the end product effluent of this process can be used as a fertilizer, as there is little or no loss of nitrogen, phosphorus, potassium or other nutrients. Thus the energy inputs and financial costs of growing the biomass substrate can be reduced. This strategy allows traceability and may give outputs compliant with the specification for quality soil conditioning and fertilising materials [19] for application to land [20].

Fermentation acts on carbohydrate rich organic material to produce hydrogen, carbon dioxide and acid end-products:

$$C_6H_{12}O_{6\,(aq)} + 2H_2O_{(l)} \rightarrow 2CH_3COOH_{(aq)} + 2CO_{2(g)} + 4H_{2(g)} \quad \text{(Equ.1)}$$

The theoretical stoichiometric yield of hydrogen is 4 moles hydrogen per mole hexose if the fermentation end products were only acetic acid, CO_2 and hydrogen (Equ.2). If butyric acid is the end product the theoretical stoichiometric yield is 2 moles hydrogen per mole hexose (Equ. 3) [15,21].

$C_6H_{12}O_{6\,(aq)} + 2H_2O_{(l)} \rightarrow 2CH_3COOH_{(aq)} + 2CO_{2\,(g)} + 4H_{2\,(g)}$ (Equ.2)

$C_6H_{12}O_{6(aq)} \rightarrow CH_3CH_2CH_2COOH_{(aq)} + 2CO_{2(g)} + 2H_{2(g)}$ (Equ.3)

The hydrogen and methane yield is subject to variation and is sensitive to environmental factors such as temperature and pH which can be controlled as part of the process and hydraulic retention time (HRT) which is substrate specific and would need to be changed depending on feedstock in order to obtain maximum yields.

1.2.2. Other technologies that could be utilized in the rural environment

1.2.2.1. Water electrolysis

The electrolysis of water using any renewable energy that produces electricity (such as solar, wind or tidal) seems to be a likely route for Wales to take given its abundance of natural resources. Electrolyser technology is well developed and works by using the renewable power input to disassociate water into diatomical molecules [22] (Eqn 4).

The Proton Exchange Membrane (PEM) electrolyser, is the most suitable for use in renewable applications as it is more able to cope with fluctuating input supply [23]. Dutton's group developed, optimised and demonstrated a wind–hydrogen production plant [23].

Water can be changed into hydrogen and oxygen using an electrolyser:

$2H_2O_{(l)} \rightarrow 2\,H_{2(g)} + O_{2(g)}$ (Equ.4)

1.2.2.2. Hydrogen from biomass

Thermochemical production of hydrogen from biomass can be split into three specific areas: Gasification, Supercritical Water Gasification and Pyrolysis. High lignin contents are required for gasification, pyrolysis and supercritical water gasification. This indicated a potential for areas with forestry and processing plants with suitable waste material. There are currently no examples of biomass being used for the thermochemical production of hydrogen in Wales.

1.2.2.3. Other Biological hydrogen production

Photosynthesis

Photosynthetic H_2 production by green and blue-green algae involves water splitting (biophotolysis) to produce H_2 and O_2. Green algae are one of the most promising groups for hydrogen production through photosynthesis [24].

Under certain conditions green algae contain an enzyme, hydrogenase, which catalyses the reduction of protons by electrons to form hydrogen. Hydrogen production is a wasteful process for these algae, but the role of the enzyme is in managing the dark to light transition that algae face daily.

Hydrogenase in green algae is only synthesised (induced) after several hours of dark preincubation in anaerobic conditions. Hydrogenase contains iron and is very O_2 sensitive so, when after a short period in light, O_2 is produced and hydrogen production rate decreases. Thus sustained H_2 production by green algae is a challenge, as biologically this system is not suited for continuous operation.

The reactor must be enclosed to allow H_2 collection and must allow good light penetration through water and the culture, otherwise cells only a few layers in may be light-starved. Increasing cell concentration for process intensification hinders light penetration.

1.2.3. Technologies with limited rural application

1.2.3.1 Steam Methane Reforming

Steam Methane Reforming (SMR) (Equ 5), as indicated earlier, is a technology already in existence in Wales and works by using a multi-stage process. Pure feedstock is passed over an active nickel catalyst typically at 850 - 900°C. This oxidizes carbon to carbon monoxide with release of hydrogen (Eqn. 6). The third stage sees carbon monoxide undergo a reaction with steam producing hydrogen and carbon dioxide (Eqn. 7) and is then purified. The process is highly endothermic.

Overall reaction:	
$CH_{4(g)} + 2H_2O_{(g)} \Leftrightarrow CO_{2(g)} + 4H_{2(g)}$	Eqn. 5
Steam reforming:	
$CH_{4\,(g)} + H_2O_{(g)} \Leftrightarrow CO_{(g)} + 3H_{2(g)}$	Eqn. 6
$CO_{(g)} + H_2O_{(g)} \Leftrightarrow CO_{2(g)} + H_{2(g)}$	Eqn. 7

1.2.3.2. Partial Oxidation (POX)

Due to the welsh heritage as a coal producing country, it is viable to use POX as a technique to generate hydrogen. The system would be sited at the pit head where the coal can be ground and mixed with water to create a sludge/slurry before gasification of the feedstock. The slurry is then heated to 1400°C in the presence of oxygen, causing decomposition, producing carbon monoxide and hydrogen (see Eqn 8). This process is then followed by shift reaction (Eqn. 9) [23, 25] producing further hydrogen.

The generic reaction for any hydrocarbon undergoing POX/ Gasification is:	
$C_xH_{y(l)} + 0.5x\ O_{2(g)} \rightarrow xCO_{(g)} + 0.5y\ H_{2(g)}$	Eqn. 8
Partial Oxidation Shift Conversion:	
$CO_{(g)} + H_2O_{(g)} \rightarrow CO_{2(g)} + H_{2(g)}$	Eqn. 9

This technique may have limited rural use where coal mining is still ongoing and road systems are maintained.

1.3. Cost of hydrogen technologies

There has been little specific research into the cost of bio hydrogen from fermentation of wet feedstock's. Where this has been undertaken the costs associated with production vary widely. From £29/GJ as reported by Tanisho [26], £9.83/GJ as a target cost as set down by the US Department of Energy [27] and £4.8 – 6/GJ as estimated by Hawkes *et al* [28]. These compare favourably with other renewable hydrogen technology [6] and are beginning to become competitive with petroleum and oil (VAT included), providing that the 0% VAT rate for hydrogen as a fuel continues. However, it is anticipated that a long-duration transition to a hydrogen economy is likely and this, coupled with the volatility of energy markets, makes it unfeasible to predict the viability of hydrogen as an energy vector with any level of accuracy.

1.4. Benefit of hydrogen technology

In the decades (since the 1970's) since the first suggestion of a move to hydrogen and its use as a fuel vector, there has been growing support and a clearer understanding of the potential benefits of hydrogen. This is due to a number of factors, firstly the ability of hydrogen to address security of supply issues though its potential to be produced using a range of methods, from renewable, biological production as well as from more traditional sources such as coal or natural gas. This, in turn, is likely to reduce dependence on imported fossil fuels. Secondly, if made using renewable or biological methods, hydrogen will have a lower carbon emission than comparable energy sources and be able to meet carbon reduction targets. Thirdly that hydrogen has the potential to overcome intermittency of renewable energy sources by allowing the storage of excess energy as hydrogen that can then be used when renewable sources are not providing enough electricity to meet demand.

Finally, it is an energy vector that can be used in vehicle (with quick refill times) as well as in the home, making it a very flexible and versatile fuel.

1.5. Literature review of other public perception of hydrogen energy studies

In order for the technology to bridge the gap between niche and mass market, the general public will have to want to buy the technology. This leads to a dichotomy - how can the general public want a product with little or no knowledge of its existence?

It has been argued by Schult *et al* [29] that there needs to be a campaign to raise awareness of hydrogen and hydrogen technology before products come to market in order to manage expectation and ameliorate public concerns.

In recent years, hydrogen technology has been more visible to the public through media reports, whilst oil companies and car manufacturers have attempted to introduce the public to the new product 'hydrogen' through advertisements. However, no coordinated effort has been made in the UK to provide the public with a coherent awareness campaign. It can be argued that no such effort can be made until the public view of hydrogen energy is understood.

Limited studies have been conducted on public perception and acceptance of hydrogen. The Accepth2 Public Acceptance of Hydrogen Transport Technologies European funded project has been active in making an initial assessment of public attitudes in Germany surrounding the introduction of hydrogen buses. Two separate reports were produced on hydrogen perception as part of the project carried out by LBST in 1998 [30] and 2003 [31].

Their first report [30] involved a three part study of attitudes towards hydrogen with students in schools and hydrogen bus passengers in Germany and a comparative evaluation of both sets of results. Part 1 of the study was carried out among 410 school students. It found that, although acceptance was high, this was restricted to some degree if the technology was introduced with higher costs. This group acknowledged the explosive risk of hydrogen but did not see this as a barrier to introduction. There was a very small deviation in acceptability between genders, with girls being marginally less accepting of the technology, despite both gender groups showing a very low scientific and technical knowledge. The initial association with hydrogen was as a chemical or indirect chemical linking - there was no indication of environmental association.

Part 2 of the study was carried out among passengers riding the hydrogen bus (no numbers were given). It found this group accepted the technology without reserve, and associated the technology with environmental benefit. Association with danger was a secondary result, with connections to the hydrogen bomb and a very small proportion (0.1%) linked hydrogen with either the Hindenburg or zeppelins. The conclusions were that both the school students and the bus passengers had a high acceptance level of hydrogen and the technology, and understood the risk of explosion. However, there was no appreciable link with disasters.

The competitive evaluation (Part 3) found that knowledge (technical/scientific) of hydrogen or of the technology does not influence the acceptability of hydrogen and there is a general interest in learning more. Learning in school had a positive affect on acceptance; it is also suggested that demonstration of the technology could aid acceptance by the general public.

The Accepth2 report [31] gives analysis and comparison of eight studies carried out in German cities, which included the technical, political and social dimensions of hydrogen. The Technical University of Berlin conducted the first of the studies examined in 1998; it investigated hydrogen vehicles and their ambience. The study was conducted in Berlin at six public locations, where 150 people were randomly selected. The study showed that there was an overall positive response to hydrogen vehicles; the main concerns of the group were vehicle and fuel cost (36%) and performance and consumption (16%), the latter again relating to cost.

Another study reviewed by the LBST [31] paper entitled 'The acceptance of hydrogen vehicles - on the use of new and novel fuel' was commissioned by the BMW group in Munich in 2000 when 1000 employees of BMW were interviewed. It found that the acceptance of hydrogen technology was high, particularly in male employees. The study concluded that general acceptance of hydrogen technology needs to be fostered and that trust and knowledge is needed in order to penetrate the mass market.

The LBST report [31] also reviewed a survey of 156 passengers of the MAN fuel cell bus in Nuremburg in 2001, concluding that the passengers strongly supported the bus due to its low noise and pollution levels and were willing to tolerate moderate ticket increases to support the introduction. This was in spite of the passengers' low technical knowledge (9 out of 10 had no idea how the fuel cell worked).

Another interesting study investigated the factors influencing the market success of vehicles powered by hydrogen. Two surveys were conducted along with, interviews with high/middle management and internet interviews [31]. This report found a generally positive attitude to hydrogen as a fuel with only limited concern over safety. The study found an overall high environmental awareness, which seemed to influence the attitude of the groups more than their technical knowledge (self graded as low/medium). It was seen that levels of education, car ownership and self-teaching were influential factors and gender had no influence.

A study by Haraldsson *et al* [32] began with the premise that "personal exposure to technology allows the public to get familiarized with the technology..." The research was carried out in Stockholm as part of the CUTE project. The work was carried out using quantitative research techniques on passengers using an ordinary bus route but riding a demonstration hydrogen bus. It was found that most passengers had a positive attitude to fuel cell buses, that cost and punctuality were the main drivers as opposed to environmental impact.

To date few UK studies [29, 33, 34] have been published in relation to public understanding/perception or awareness of hydrogen. A quantitative study [33] on London's black cab drivers found that environmental considerations affected taxi drivers' long term purchasing decisions. Schulte *et al* [29] focused their study on creating a model for hydrogen acceptance. Although not an acceptance study, it provided an interesting background and insight into the development of people's perceptions and developed a model where areas of influence are highlighted. It showed that one of the easiest ways to influence perception of hydrogen is through product exposure, thus engendering a trust in the technology.

The analysis of awareness and acceptability of hydrogen vehicles by O'Garra *et al.* [34] in London is the first study that has a statistically valid group; as all other studies had been conducted using convenient subject groups.

The study found that less than half of respondents had heard of hydrogen as a transport fuel and concluded that the safety worries of the respondents were not as high as they had expected with only 20% associating hydrogen with safety concerns. It may be noteworthy that this study was conducted prior to the introduction of the CUTE hydrogen buses to London.

The majority of those people who did support the introduction of hydrogen vehicles had some prior knowledge, a factor which has been highlighted by other studies [31]. The study also established that gender had a large influence on the acceptability of the technology with men being more supportive than the women questioned. The idea that there are gender differences between acceptability challenges the German LBST studies [30, 31] in Berlin and Munich respectively which found no link between gender and support. The different findings could be due to cultural differences between the three European cities [35].

The O'Garra *et al* [34] study concludes that there is a need for more information to be made available to the public, as up to 60% of the respondents indicated that they needed more information before making a decision.

The work presented here represents the first public perception work within Wales to be undertaken using qualitative methods. It was undertaken in 2004 and published in 2008 in Public understanding of Science [36]. The work reported here forms part of a study on the implications of a move towards the hydrogen economy in Wales. It is a first step towards establishing social attitudes to the use of hydrogen energy in Wales and towards the development of an appropriate awareness program.

Subsequent to this work Ricci *et al* [37] conducted qualitative work between 2005-6 in Teesside, South West Wales and Greater London. These results indicated that there were a number of interconnected issues that related to whole supply chains. Specific concerns related to safety and the environment, which were expressed abstractly by the focus group participants.

The DfT Horizon Research Programme published a qualitative study [39] which identified the public's attitude to hydrogen technology. It found that people's opinions had yet to form on hydrogen energy and that some issues, particularly those related to risk, were predominantly neutral with more information needed. It is worth noting that people particularly in this study were more inclined to prefer the use of renewable technology to generate hydrogen than utilising nuclear or traditional fossil fuels. The study also found the public need to be reassured that distribution methods would be safe, but were otherwise accepting.

The other work by Ricci *et al* [40] reviewed the public perception research techniques employed in the field of hydrogen research and concluded that more qualitative research needs to be carried out. Ricci et al argued that more qualitative research is required to address the gaps in our understanding of the public's knowledge and opinions on hydrogen energy and technology. It should be noted that the public perception work presented here formed part of the body of knowledge reviewed in this paper.

A number of quantitative studies have been conducted, including Achterberg [41], Tarigan [42] and O'Garra [34]

Achterberg *et al* [41] did quantitative research and investigated whether there was a direct link between knowledge of hydrogen and high acceptance of hydrogen technology or whether it has a more cultural dimension. The work concluded that, if cultural ethics relating to environment, stewardship and trust in technology are high, then there is a general trend for there to be a positive view of hydrogen. However, where there is a cultural lack of care for the environment a view of nature as a commodity, then there is low support for hydrogen technology which was not significantly changed despite additional information. Achterberg [41] concluded that additional knowledge was only linked with increased support where cultural predisposition was present.

Tarigan *et al* [42] was influenced by the work of O'Garra *et al* [34] and found, using quantitative surveys, that in the case of Stavanger (Norway) that greater knowledge of hydrogen refueling and infrastructure correlated with a lower support rate, unless it was accompanied by a supportive attitude to sustainable environment in which case the converse is seen and there is a greater support for the applications of hydrogen vehicles and refueling stations.

In order to facilitate the transition to a hydrogen economy it is important that we understand the challenges and likely concerns that the general public will have with hydrogen technology. Current literature would indicate that key areas of interest will include safety factors, environmental sustainability, cost and production methods. It is clear that there is a significant challenge to confront in terms of public information provision and public acceptance before the widespread adoption of hydrogen energy can take place [34].

1.6. Affects of social grade and age on the attitudes to science and technology.

Research suggests that social grade and age can have an influencing affect on people's attitude to science and technology [43,44,45,46]. This study did not set out to assess the effects of social grade on hydrogen technology acceptability due to the very small sample size (see section 3). It is, however, worth bearing in mind this influence when considering the results. The following section reviews the research carried out in this area. For convenience, a definition of social grades has been included at Appendix 3.

There have been a number of comprehensive studies looking at how the general populous views science and technology and this includes work carried out by the Wellcome Trust [43], Royal Society [44], Research Council UK [45] and MORI[46]. These studies have been conducted over a number of years to determine the overall public attitudes to science. The Wellcome Trust published the first of these studies in 2000 [43] and found that the public were split into six groups:

- confident believers,
- technophiles,
- supporters
- concerned ,
- not sure and
- not for me.

In the case of the "supporters" and "concerned" groups, these were reflective of the broad population base and demonstrated no readily-identifiable features except that there were slightly more women with families in the concerned group. Where the respondents were of low social grade, and low educational background they were generally found to be "not sure", whereas the "not for me group" was characterised by older (65+) low social grade women and younger C2 men.

It was found, however, that there was a strong link between education and support for science and technology: the better educated the respondent the more likely they were to be confident believers or technophiles (and in the case of older respondents in this category they were more likely to fit into the former group).

A subsequent study in 2005 [44] found that:

• Those aged 25 and over tend to be more interested and engaged with scientific topics than younger people;
• Those from social grades ABC1 tend to be more interested and engaged with scientific topics than those in social grades C2DE.

It was suggested that this distinction may be more to do with level of education than necessarily solely down to social grade. This is an interpretation that is in agreement with the findings of the Wellcome Trust study [43].

A review of public attitudes to science in 2011 [46] concluded that those with a higher educational level and social grade AB were more confident about science, whereas social grade DE were less confident and had the lowest educational level of any of the groups. This report also concluded that there was more interest and confidence in science in the 25 - 60 year age range, where the younger demographic were at ease with technology, though untrusting of the benefits. The 60+ age group was more inclined to feel that science and technology were progressing too quickly.

Overall it has been found that the level of education of an individual is the key factor in their acceptance of science and technology, with social grade and age a further, but lesser, influencing factors. Furthermore, the individual's belief in the personal and social usefulness of science and technology alongside the level of trust in authority were seen to be influencing factor.

Within this context of age social and educational background, it is important to consider that discrimination between groups requires significantly larger sample sizes than that typically used in an early study such as that reported by

Cherryman et al [36]. The available resources, stage, type and objectives of the study are all mitigating influences on the design of the study (discussed in section 4.2.2.3.). It is interesting to note that despite the lack of age, social and educational resolution, the methods and conclusions of the study by Cherryman et al, have been used in later studies e.g. Flynn et al [38] and Bellaby et al [39]. The acceptance of hydrogen as a fuel is a dynamic issue and has been influences by press and research and commercial developments in transportation recently.

1.7. Other factors which may impact acceptance of hydrogen

Anaerobic Digestion (AD) technology is the closest technology to the dark fermentation approach studied here. This technology has had issues in the past where AD plants have had a negative public image due to odour issues [47]. However, some research has suggested that this may be because of the feedstock and not necessarily the technology itself [48]. Where feedstocks were labelled as bio-waste or waste (i.e. kitchen, industry food waste or slurry) there were negative associations (particularly to the idea of contamination). Energy crops, agricultural material and wood were seen as 'clean' and could attract a higher premium for its 'green' credentials [42].

So far in all the hydrogen research that has been published, no concerns with odour have been raised. This may be down to the feedstocks that have been proposed having had a 'clean, green' image. The issues that AD faces may begin to encroach into the bio hydrogen arena as soon as the use of waste streams for feedstock (solely or partially) becomes more common, as may be the case where it is used with waste water or industrial food waste. However, it is expected that in full scale operations, odour control mechanisms and good methanisation would minimise odours in the plant and of the digestate.

A further area of challenge could come with the competition between energy crops and food. According to Skipper *et al* [49] the general public has a preference for cheap food to cheap fuel. As such there is likely to be competition for land use. This could be overcome through the reintroduction and use of set aside land. If this was not to be forthcoming it would be expected that market economics would drive the most profitable use of the land. With gate fees dropping for AD plants treating wastes, the scenario of digesting energy crops may be seen more favourable in the UK in the future.

2. Methodology

2.1 Overview of process

The aim of this research is twofold. Firstly, to assess the potential for Hydrogen production, using anaerobic dark fermentation in Wales. This assessment will be conducted by determining the relative effectiveness, measured in terms of energetic output, of a range of crop-derived feedstocks. The crops selected for assessment will be limited to those either traditionally grown in Wales, or which have shown particular promise in trials in equivalent climates.

Secondly, an assessment of the public perception relating to the generation and end-use of hydrogen as a fuel stock/energy source will be conducted to assess the acceptability of wide scale implementation of this technology.

Bringing together these two themes will determine whether dark fermentation technology for hydrogen production in Wales, without significant changes to existing farming practices, is both energetically feasible and whether a diversification in farming practice to support this emerging technology would be supported by the public.

In order to simplify the identification of the optimum energetic feedstock for hydrogen generation, commercial and cost considerations have been omitted from this study.

This work was carried out as part of the EPSRC supergen project.

2.2. The bio-hydrogen net energy calculations methodology

The process proposed is similar to that already in use with anaerobic digestion of animal waste to methane: The farmer will use existing sowing, growing and harvesting technologies, together with their experience to minimise energy input. The crops selected are indigenous or have been shown to grow in similar climates.

It is assumed that the crops will be grown and used on site, avoiding transportation, and that the crop will be harvested immediately before use, thereby avoiding deterioration in substrate qualities. It is further assumed that crops receive no pre-treatment other than harvesting.

Optimal crop identification will be achieved by assessing the range of crops and identifying those with a high yield, suitable harvest window, minimal energy input and optimal composition for the production of hydrogen. From this data, a comparison of energy yields will be conducted in order to identify the crop type with the largest net energy output.

Net energy output will be determined on an annual basis, thereby allowing a range of crops with different harvesting windows to be used: the reactor operates at optimal efficiency when it is used for as many consecutive days as possible. Any break in production will require restart which can take days to return the reactor to working efficacy. This drives a requirement to identify harvest periods that complement each other, thereby ensuring continuous supply of feedstock.

A further requirement in identifying an optimal crop range is the need to ensure that selected crops have similar processing requirements. This ensures that the reactor is sized appropriately - a crop that had a high yield and short harvest window would drive a large reactor design that would lead to underutilisation (and low levels of efficiency due to higher levels of energy input required to maintain the reactor) for the rest of the year. Crops with long or complimentary harvest windows, along with similar yields and hydraulic retention time (HRT) drive a smaller reactor size but retain a higher overall level of efficiency.

2.2.1. Identification of land available

Land availability has been calculated by identifying the amount of usable land as derived from agricultural databases and contacts [10, 50], and determining an appropriate % conversion to energy crop production based on historic agricultural subsidies. In this case the 8% European set aside rate of 2005-6 [49]. Subsequent to this work being carried out, the set aside scheme has been removed.

2.2.2. Crop growth and selection

Candidates for energy crops to be grown in the UK were subjected to a systematic selection process to identify the most suitable crops for anaerobic fermentation and their ability to fit within current agricultural practices.

All crops selected can grown in UK climatic conditions, although trials on sweet sorghum are continuing.

Table 2.1. Crops considered for selection:

Barley
Flax
Fodder Beet,
Forage Maize
Hemp
Miscanthus
Oats
Perennial Rye Grass
Potato
Reed Canary Grass
Sugar Beet
Sweet Sorghum
Switch Grass
Wheat (whole crop).

The criteria for crop selection were productivity levels (tonnes per ha), carbohydrate content of the crops (% dry and or fresh matter of harvested crop) and harvest windows. All of the crops selected comply with set aside rules, and can be grown and harvested using standard agricultural machinery and practices.

2.2.3. Compositional data

Hydrogen production via anaerobic dark fermentation requires that crops are readily biodegradable. Carbohydrate-rich organic material, low in lignin, is the preferred substrate, though hydrogen production by fermentation can utilise a wide range of carbohydrates.

Compositional data of the crops were tabulated and recorded; with either % dry and /or fresh matter.

Table 2.2. Compositional data to be recorded for crops

Soluble Sugars	% dry and/or fresh matter
Starch	% dry and/or fresh matter
Water-Soluble Carbohydrates	% dry and/or fresh matter
α-Cellulose	% dry and/or fresh matter
Hemicelluloses	% dry and/or fresh matter
Pectins	% dry and/or fresh matter
Lignin	% dry and/or fresh matter

In cases where dry matter information was not available it was derived using published water content data for the crops. Where no compositional data was available the field was left blank. α-cellulose, hemicellulose and pectins were recorded as they can be degraded to produce methane and, potentially, hydrogen. In cases where there were multiple results the mode was taken.

2.2.4. Harvest windows

The harvest windows of the crops were recorded and plotted using published data for all crops selected. Where crops could be harvested and stored with slow degradation of carbohydrates, these were also recorded. This was to ensure continuous supply to the reactor, and maximum annual reactor use.

2.2.5. Calculations of hydrogen and methane yields

The following assumptions were used to calculate hydrogen and methane yields expected form the system.

Table 2.3. Assumptions used to calculate energy output

Assumption	Rationale
hydrogen yield of 1.7 mole hydrogen per mole hexose for sugar beet	This was experimentally verified by Hussy[13] for sugar sources
1.9 of hydrogen per mole hexose for starch	Experimentally verified results[15]
yield of 0.7 moles hydrogen per mole hexose (assuming all total sugar is hexose) for perennial rye grass	[14]
95% of fine particulate wheat starch and 90% sucrose from sugar beet is converted to hydrogen and fermentation end products	This is experimentally verified data. By allowing the assumption that 95 or 90% is converted we can assume hydrogen production [15] [13]
a hydraulic retention time of 12 hours operating on starch	This allows the calculation of processing time of hydrogen and crop harvesting schedule.[14]
HRT 15 hours sugar beet	This allows the calculation of processing time of hydrogen and crop harvesting schedule [51]
HRT 20 hours grass	This allows the calculation of processing time of hydrogen and crop harvesting schedule
Substrates in the influent at 50 kg m^{-3} (dry matter)	Together with HRT this allows the calculation of optimal reactor sizing. [52]
A hydraulic retention time of 15 days for the methanogenic anaerobic digester	This is required for reactor sizing and energy requirement [52]
90% of the acetic and butyric acid resulting from the hydrogen fermentation is converted into methane.	To calculate the methane production this figure is combined with methane yield
The methane yield from the holocellulose entering the anaerobic digester after the hydrogen fermentation stage is on average 0.3 m^3 methane per kg volatile solids added	[51]

Assume 1 mole hexose degraded in H_2 stage gives 0.5 mole acetate (hence 0.5 mole methane in anaerobic digester stage), and 0.75 mole butyric acid (hence 1.9 mole methane in anaerobic digester stage)	[52]
No conversion of cellulose to hydrogen by clostridia takes place	[53,54,55]
The size of a medium to large farm scale plant was calculated for a 250 ha farm operating using substrate grown on 20 ha cropped for 10 months of the year.	
The reactor sizes were 7.5 m^3 for the hydrogen reactor and 110 m^3 for the methane reactor	Using the above assumptions it was possible to determine the following reactor sizes

2.2.6. Total energy ration

The overall net energy production for a crop grown on one hectare of land was calculated using the equation below (see Appendix 4 for derivation).

$$E_N = Y_c\left[WSC\ S\left[(Y_{H2})(H_{2\,LHV}) + \left[(Y_{ac}) + (Y_{bu})\right]CH_{4\ LHV}\right] + \left[\%CHC \times CH_{4\ LHV}\right]\right] - E_I - E_2$$

where,

Y_C=Crop yield (t ha^{-1} dry matter)

WSC S= Water soluble carbohydrates and starch (% dry matter)

Y_{H2}=Reported H_2 yield for specified crop (moles hydrogen per moles converted)

$H_{2\,LHV}$= Hydrogen low heating value (120 MJ kg^{-1}) [6]

CHC= α-Cellulose and hemicellulose (% dry matter)

Y_{ac}= Reported methane yield from acetic acid yield (moles methane per mole acetic acid converted) [14]

Y_{bu}= Reported methane yield from butyric acid yield (moles methane per mole butyric converted) [14]

$CH_{4\,LHV}$= Methane low heating value (50 MJ kg^{-1})

E_N= Net energy (MJ ha^{-1})

E_I= Energy Input to grow the crop (MJ ha^{-1})

E_2= Energy to run the process (36 MJ yr^{-1}) quoted in [56]

2.3. Public perception

The public perception work reported here was carried out as part of an EU-supported project – A sustainable energy supply for Wales: towards the hydrogen economy (www.h2wales.org.uk).

This area of the study was conceived and organized by myself, but was carried out in part by the research firm People Science and Policy (PSP) under contract to the University of Glamorgan. The use of an external agency was deemed necessary in order to reduce the potential bias that the interviewer may bring to the process and due to time constraints on the research.

The public perception relating to the generation and end-use of Hydrogen as a fuel stock/energy source was conducted to order to determine the level of acceptability of both the generation of hydrogen fuel from bio-hydrogen production technologies and the end use applications.

The study used qualitative research techniques to determine the public perception of hydrogen; this was done by selecting a range of individuals to participate in focus groups. It was the intent of the study to have representatives from all social grades present during the study.

A focus group-led approach was selected as it provided a range of advantages over quantitative studies that have been carried out in the past when conducting hydrogen research. This includes the ability to explore concepts and ideas beyond that typically achieved with questionnaires, by allowing the participants to fully explore the topics, and bring out issues that the researcher had not anticipated, but which are relevant to understanding public concerns and issues.

The perception that views and opinions are derived from social interaction, both casual and within structured environments such as the focus group-based approach adopted here, aligns with a symbolic-interactionist (SI) approach.

A symbolic-interactionist interpretation defines a three-stage process in opinion forming: firstly that individuals attach meanings and values to concepts and objects and act on the basis of these values; secondly that these values are informed by the interaction the individual has with the wider society; and thirdly that these values may change over time in response to the experiences of the individual. (Blumer, 1969) [57]).

The recruitment and first session was conducted by PSP under instruction from myself, the second session was headed by a PSP employee and myself. The results of both sessions were reported back to the University via a comprehensive report, which I interpreted in light of past research and as part of the results and work carried out by myself in relation to bio-hydrogen technology. The report can be found at Appendix 5.

The participants lived in South East Wales, a region with 60% of Wales's 3 million population. A simple questionnaire was utilized by the recruitment firm, covering age and social grade, to ensure a spread of participants.

The study was carried out in October 2004, in 2 two-hour slots involving 16 individuals. One major shortfall of this study is that during the tendering process, the full transcripts were not included as a contract deliverable. This in turn severely reduced the amount of analysis that it was possible to carry out.

Table 2.4. Age and social grade of participating men

Age	Social Grade
34	E
25-55	D
42	D
25-55	C1
25	C1
25-55	B
25-55	B

Table 2.5. Age and social grade of participating women

Age	Social Grade
45	D
25-55	C2
55	C2
38	C1
25-55	C1
25	C1
48	C1
25-55	C1
25-55	B

It was the intention to gain participants from all social grades. However, this was not achieved, possibly due to the higher social grades having less of an incentive to participate due to time constraints or the monetary incentive not being adequate.

Members of environmental groups, the energy industry and the media were excluded from the study as being more likely to hold strong views that may not be typical of the lay public.

Participants were paid £60 GBP by the recruitment firm to participate in the study.

The venue, a mid-range hotel, was chosen to be neutral and non-threatening. The groups were separated by gender as it has been noted that women can feel intimidated by men in group situations, and can feel reluctance to discuss technological/scientific subjects [58, 43]. It may also be expected that men and women have different priorities and concerns in relation to technical and scientific issues [58, 38]. This gender grouping, together with socio-economic and age ranges, provides a broad view of perception among the population in South East Wales.

In the first sessions the groups were led by a facilitator who provided the Office of Science and Technology briefing notes on the hydrogen economy along with some basic information [59] and some more general information from the University of Glamorgan, specifically the author of this report (see Appendix 6).

The facilitator prompted the group with some general topics and questions provided by the author (see Appendix 7) and the group was then allowed to continue to talk with the facilitator probing relevant issues as they were raised, until the arguments were exhausted. This method allowed the study to draw out the complex picture associated with the image and perception (symbolism) of hydrogen and hydrogen technology. The end of the first session was used to gather questions to be answered by an expert at the second sessions.

The second session was structured around answering the questions raised by the group the previous week, which the expert (the author) did, aided by a selection of photographs (Appendix 8). The session format allowed participants to ask new questions, raise new issues and reflect on and debate the information provided and previous discussions, enabling them to integrate the ideas within their own perceptions of hydrogen (as would be expected within the framework of Symbolic Interactionism).

The participants completed a self-assessment questionnaire to provide information on their attitudes to science and the environment. The questions were taken from *"Science and the Public: a review of science communication and public attitudes to science in Britain".* See Appendix 9 [43].

3. Results

3.1. Identification of land available

Table 3.1. Agricultural land use ('000 Hectares)

	Scotland [60]	England [61]	Wales [62]	N Ireland [63]
Total Agricultural land	5197	9583	1639	1074
Arable land				
Tillage and grass (under 5 years old)	965	4499	183	191
Permanent grassland (over 5 years old)	903	2816	962	710
Rough grazing	3329	612	406	153
All other agricultural land	-	1369	5	17
Set aside	76	287	4	3

The scenario considered ranges from a realistic 8% set aside converted to an overly optimistic scenario of 8% of permanent grassland converted to energy crop growth. This equating to 14,640 ha set aside and 76,760 ha permanent pastures in Wales.

"Set aside" land is left fallow or used for growing non-food crops with industrial uses. For 2005 the percentage to be set aside was 8% of all agricultural land, excluding permanent pasture and rough grazing [64] This is the figure used here. Farmers are able to grow crops on set aside land which are not for human or animal consumption. No existing arable land has been included since energy crop production may not be cost effective.

3.2.Crop selection for dark fermentation

Table 3.2. Average yields of crops in temperate climates (e.g. UK and N. Europe)

Crop	Yields t ha^{-1} (fresh)	Yields t ha^{-1} (dry matter)	Reference:	Country
Barley	5-6	4.25-5.1	[65]	UK
	5-7	2.75 straw	[64]	UK
	4.53		[66]	UK
Flax	4-8	3.7-11.6[a]	[65]	UK
Fodder Beet	80		[64]	UK
	80-100	13.6-17	[65]	UK
Forage Maize		17-21	[67]	Ireland
	40		[64]	UK
Hemp	5.5	4.54[b]	[64]	UK
	8-12	6.6-9.9[b]	[65]	UK
Miscanthus	15		[65]	UK
		11-18	[68]	UK
		7-24	[69]	UK
		12-14	[64]	UK
		12-30	[70]	UK
		11	[71]	UK
Oats	5.5	4.7	[65]	UK
	5.25-7.75	3.5 straw	[64]	UK
Perennial Ryegrass	10-20		[65]	UK
		8.5-19.2	[72]	France
		15	[73]	The Netherlands
		12	[74]	UK
		18-23	[75]	UK
Potatoes	40		[65]	UK
	36-44-52	2.3-3.4[c]	[64]	UK
	32		[66]	UK
Reed Canary Grass	12-18		[65]	UK
		7-8	[71]	UK
Sugar beet	55	12.65-13.53	[65]	UK
	40		[66]	UK
	34-60		[76]	UK
	45-80		[77]	UK
	42.5-55-67.5		[64]	UK
Sweet Sorghum		20-27	[78]	(Northern) Italy
		25	[65]	UK
Switch Grass	12-18		[65]	UK
		8-13	[71]	UK
		9	[79]	Iowa (USA)
		8	[70]	UK
Winter Wheat	7-9		[65]	UK
	5-7		[66]	UK
	6.7-8.25-9.75	3.5 straw	[64]	UK
		14 (whole crop)	[70]	UK

Table 3.2. shows fodder beet (13.6-17), forage maize (17-21), miscanthus (7-30), perennial rye grass (8.5-23), sugar beet (12.65-13.53), winter wheat (whole crop) (14) and sweet sorghum (20-27) have the highest yields

3.3. Compositional data

Table 3.3. Composition of prospective crops (Expressed as % dry matter (dm) or fresh)

Crop	Soluble sugars	Starch	WSC[a]	Pectin	α-cellulose	Holo-cellulose	Hemi cellulose	Lignin	Ref
Barley		55.1dm				13.7dm			[80]
Flax				3dm	65dm		16dm	2.5dm	[81]
					72dm		18dm	3dm	[82]
Fodder Beet	12.2fresh		63.9dm						[83]
Forage Maize (whole plant)			22.1dm		30.3dm		19.5dm	4.8dm	[82]
			25.4dm		36.8dm		27.4dm	5-8dm	[82]
		31dm				36dm			[84]
Hemp	5-6dm				69-74dm			1.5dm	[85]
					67dm		16dm	3.3dm	[81]
				3dm	73dm		7.6dm	3dm	[82]
Maize					33.2dm		24.6dm	15.1dm	[82]
Miscanthus					57.9dm		16.1dm	8dm	[82]
					44dm		24dm	17dm	[86]
Oats (grain)		54-64dn							[87]
			48dm			6.1dm			[80]
					34.9dm			4.3dm	[88]
Perennial ryegrass	25.3dm	3dm			(57.5dm)b				[89]
Potatoes		85-87dn							[90]
Reed canary grass					28dm		22dm	14dm	[91]
					28-34dm		20-23dm (including pectin)	7-18dm	[92]
Sugar beet	15.5-18 fresh								[93]
					26dm		28dm	4.5dm	[82]
	17.10 fresh			21.75dm	29dm		21.75dm		[94]
	14-15 fresh								[95]
	17 fresh								[96]
	17 fresh 64.7-70dm				4.9-6.3dm				[65]
Sweet sorghum	15.8 fresh				5.5fresh		4.5fresh	3.3fresh	[97]
	43.58dm				25.1dm		22.34dm	3.8dm	[78]
Switch grass					30-50dm		10-40dm	5-20dm	[70]
					31.6dm		36dm	6.1dm	[79]
	5.5dm	5.65dm							[98]
Wheat straw					33.2dm		24.6dm	15.1dm	[82]
Wheat whole plant		10.5dm			33.7dm		13.4dm	7.5dm	[82]
					33-40dm		10-40dm	15-20dm	[70]

[a]WSC, Water soluble carbohydrates
[b]Combined value for α- cellulose, Hemi-cellulose and lignin = 57.5dm

Hydrogen production requires high carbohydrate concentration. As can be seen from table 3.3, the crops with the highest content of soluble sugars are sweet sorghum, perennial rye grass, oats, sugar and fodder beets. The highest starch contents were found in potatoes, oats, barley and fodder maize. In most cases where crops contain a large amount of cellulose and hemicelluloses (ranging from 13%-74% dry matter) methane production is achievable. It can be expected that the crops with high lignin content such as reed canary grass, miscanthus and wheat (whole crop and straw) are likely to be problematic to ferment to hydrogen and methane production.

3.4. Harvest windows

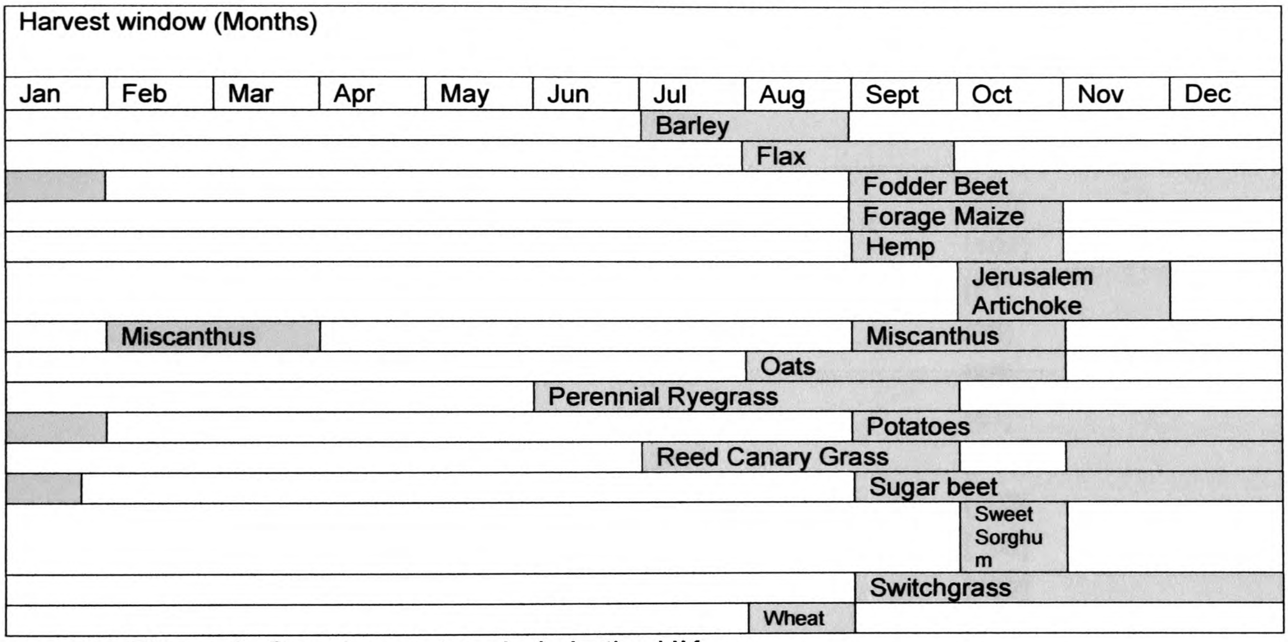

Figure 2. Crop harvest periods in the UK

The harvest windows of the crops are important in maximising the number of days per year that the fermentation process could operate. The harvest windows indicate when crops can be used in the fermentation process directly after harvesting, or stored for later use. During April and May there are no reported harvest activities. Only miscanthus could be harvested during February and March. Some crops can only be harvested in one month (wheat and sweet sorghum), whereas other crops like beets, perennial rye grass or potatoes have a longer period for collection

Of the crops indicated it is possible to store sugar beet, forage beet or energy grasses for a short period (however they will convert the sugars to starch at a rate of 10 % per month stored). Crops cannot be stored by conversion to silage, as in this process carbohydrates are converted to fermentation end products and hydrogen will not be produced.

3.5. Energy Inputs

Table 3.4. Energy inputs per hectare per year from annual cropping

	Energy inputs (MJ ha^{-1})	**Reference**
Barley	16,563	[99]
Flax	8,656	[100]
Fodder Beet	18,247	[99]
Forage Maize	17,630[b]	[101]
	23,920	[102]
Perennial Rye Grass	4,710	[103]
Hemp	12,234	[100]
Maize	17,630	[101]
Miscanthus	6,234	[51]
Oats	15,094	[99]
Potatoes	48,200	[99]
Reed Canary Grass	4,082	[51]
Sugar Beet	18,247[b]	[100]
	21,400	[103]
	20,240[a]	[102]
Sweet Sorghum	18,400[a]	[102]
Switch Grass	6,330	[51]
Wheat	21,895[b]	[99]
	23,920[a]	[102]

[a] Modified so that average yearly figure is obtained.

[b] Figures used for calculation of net energy calculation.

Energy inputs range between 4,082 MJ ha^{-1} for reed canary grass to 23,920 MJ ha^{-1} for wheat or forage maize. High energy input will degrade any yield benefits. Energy inputs needed to grow and harvest the crops the data includes agrochemicals (including pesticides and fertilisers) and machinery activities (ploughing, harvesting etc.) but not transport or storage.

Miscanthus, reed canary grass and switch grass have been averaged over their expected lifetime (20 years) [104] as energy inputs in the early stages of growing these crops are very high, but once established reduce dramatically.

Data energy inputs given in references [99, 100, 103] have been reduced by 8% to compensate for added transportation energy.

3.6. Calculations of hydrogen and methane yields

Table 3.5. Calculated gross and net energy output

	Energy output from H_2 MJ ha^{-1}	Energy output from CH_4 MJ ha^{-1}	Total gross energy output MJ ha^{-1}	Net energy output MJ ha^{-1}
Barley	5,653	29,522	35,175	18,613
Flax	0	45,441	45,441	36,785
Fodder Beet	19,263	116,046	135,309	117,063
Forage Maize	13,429	125,723	139,152	121,522
Hemp	829	62,419	63,248	45,618
Miscanthus	0	97,767	97,767	91,533
Oats	5,733	26,812	32,545	17,451
Perennial Rye Grass	3,140	115,759	118,899	114,189
Potato	7,259	27,737	35,037	-13,163
Reed Canary Grass	0	38,250	38,250	34,168
Sugar Beet	18,853	112,017	130,871	112,624
Sweet Sorghum	22,685	219,642	242,327	223,928
Switch Grass	2,338	73,180	75,519	69,190
Wheat (whole crop)	3,351	81,081	84,432	62,538

The highest net energy yielding crops are sweet sorghum (223,928 MJyr ha^{-1}), forage maize (121,522 MJyr ha^{-1}) sugar beet (112,624 MJyr ha^{-1}), perennial rye grass (114,189 MJyr ha^{-1}) and fodder beet (117,063 MJyr ha^{-1}).

3.7. Total energy ration

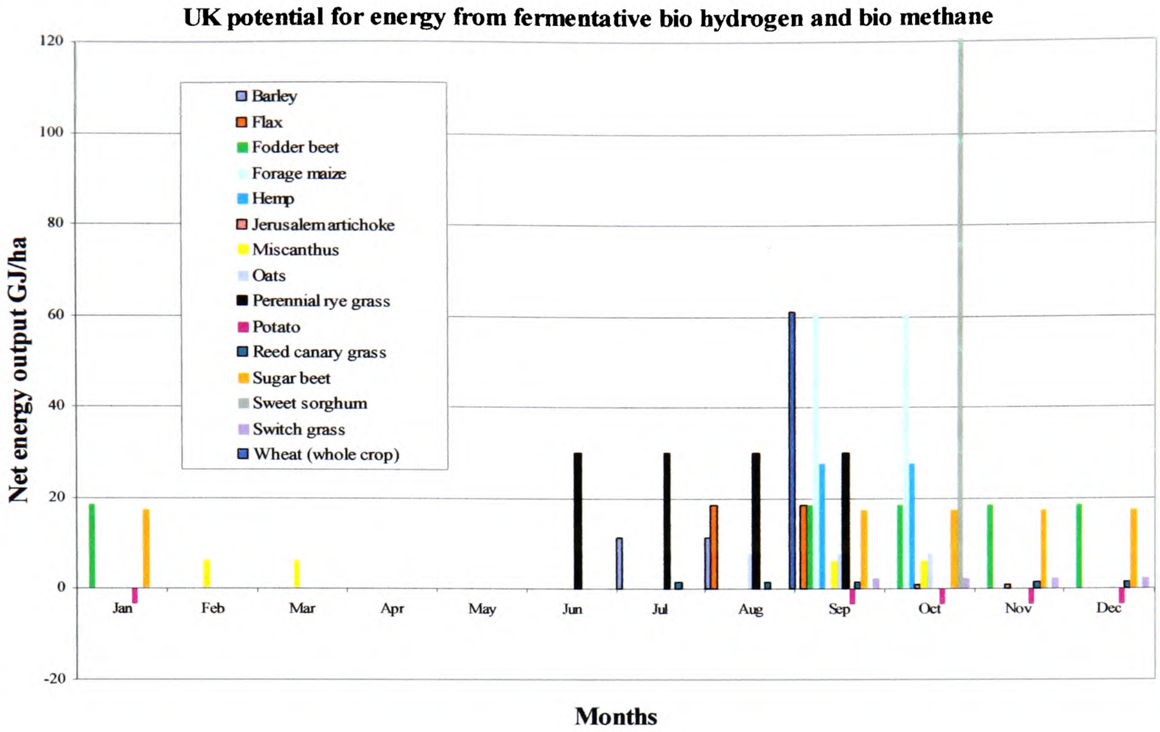

Figure 3. Harvest periods v Net Energy Output/ha for a range of crops grown in the UK

The most consistent crops in terms of energy output over the widest harvest period are sugar beet, fodder beet, forage maize and perennial rye grass.

3.8. Public perception (session 1)

The following results were taken from the report prepared by PSP for the University of Glamorgan as per the contract agreements set in place during the tendering procedure. The raw data was not available due to an oversight in the tendering procedure and as a result the data analysis options have been limited.

The results are broken down into male and female responses and not by age or social scale due to the methods employed in data gathering (Primarily due to the fact that it was not possible to ascertain individuals from the audio tape recordings).

This study did not seek to obtain a statistically valid sample size that would allow the views to representative of a larger populous due to budgetary and time constraints. The methodology adopted does however allow for a more in-depth discussion on the topic of hydrogen than can be achieved using questionnaires.

The techniques employed within this study allowed an explorative of participants understanding and opinions on a range of hydrogen themes, based on their experiences, beliefs and values. The participants could then incorporate the understanding, opinions and experiences of the other members of the group in order to reframe their own opinions as would be expected under SI theory.

The results are presented by giving a synopsis of main issues followed by a breakdown of examples of discourse, the results of which are presented in the order in which they were discussed. The results are presented in line with the convention of presenting focus group results.

3.8.1. Synopsis of the focus group findings.

The main concerns of both the female group and male group were safety (both of use and in production) and cost. There was a general feeling that hydrogen would illicit concern within the general populous. The groups did not see safety as a drawback from introduction as they believed that it would be more of a case of 'getting used to it' and learning how to deal with it safely.

Cost was a more pressing issue to the participants, in that they felt that if the technology was expensive in comparison with 'normal' technology the uptake would be limited to those doing it for green credentials.

There was general support to hydrogen being generated from renewable sources, and not transferring the pollution problems 'somewhere else' as would be the case with fossil fuel derived hydrogen. Dark fermentation technology was seen as addressing these concerns relating to pollution being moved to production sites.

Where hydrogen was discussed, it was as part of a set of expectations, presuppositions and in relation to the participant's core values and experiences.

This links with the underlying theory that people frame their core understanding using symbolism these were expressed by layering their knowledge of hydrogen with concerns for the future (environmental and energy acquisition) hopes for technology fixes, the need for an economical product combined with framing within complimentary experiences (e.g. transition of vehicles to LPG) and historic comparisons (e.g. transit ion from town gas to natural gas).

3.8.2. Attitudes to science

Table 3.6. Results to attitude to science questionnaire.

The statement	Male Positive response	Male Negative response	Female Positive response	Female negative response
"I am not interested in science and I don't see why I should be"		100%		100%
"science and technology are making our lives healthier, easier and more comfortable"	100%		89%	11%
"the speed of development in science and technology cannot be properly controlled by the Government".		100%	11%	89%

The above results were based on 7 male respondents and 9 female respondents.

3.8.3. Understanding of hydrogen

Participants' understanding of hydrogen was ascertained. From the results presented it would appear that men had a more negative attitude to hydrogen than women. Although both groups associated hydrogen with the elemental nature of a gas for a few men it related directly to explosion, bombs and the Hindenburg. The women were generally less inclined to offer up information on the nature of hydrogen one did identify hydrogen with hydrogen peroxide this was likely to be due to her experience as a hairdresser. There was a consensus as all participants were conscious of hydrogen and oxygen being associated with water.

Initially, there was a lack of awareness of hydrogen as a fuel vector or its potential use as a transportation fuel. The majority of the initial responses to the question related directly to the nature of hydrogen as a gas.

The exceptions to this were:

Table 3.7. exceptions within the groups

respondent	knowledge
Male	Some understanding of a connection of hydrogen and fuel cells
Female	Recollection of a article in newspaper relating to hydrogen as a transport fuel

During the course of discussing hydrogen there was some confusion among the male group where one participant confused Hydrogen and Helium and another where a male participant thought Hydrogen had a "half of a bad smell" this could be due to Cardiff being relatively close to the steel production site in Port Talbot that is synonymous thought the area with a hydrogen sulphide odour.

Prompting the groups with mock headlines relating to the introduction of a hydrogen bus in Cardiff this allowed for the development of ideas and prompting of knowledge.

This resulted in a belief that cars and buses running on hydrogen (fuel cells) would be quieter than standard vehicles (either through knowledge or expectation).

Additionally within both groups the participants were then able to interact and develop their expectations. There was a general expectation that there would be no visual differences between hydrogen busses and normal busses, and that this would be a desire within the manufacturing community to make them appear 'normal'.

Within both groups personal experience of vehicle modification to Liquid Petroleum Gas (LPG) lead the participants to believe that a transition to hydrogen would not necessitate a change in appearance.

There was a belief that hydrogen fuelled busses would be better for the environment.

"It is a clean fuel."

Man

"The only emission is water and there is an abundant supply of hydrogen."

Man

Although the emission of water as an end product reassured some participants of the fuels clean, environmental nature. The free exchanges of ideas lead to one man questioning the wisdom of using hydrogen.

"If there is more hydrogen in the air won't that combine with the oxygen and produce water?"

Man

This led the rest of the group to then question and debate the possible impact of emissions on the local climate. There was some debate as to whether it would encourage damp environments or if it would increase precipitation.

3.8.4. Supply

The supply issues raised encompassed two separate trains of thought the first related to the security of supply of hydrogen fuel and; second related to the access at forecourt level of the fuel.

There were three general feelings about the conventional fuel petrol that were key to the participants views of hydrogen fuel, these were:

- awareness of problems with the supply of petrol (in terms of the location of oil supplies and a perceived monopoly by the oil companies)
- a belief by the women that we as a society have a dependence on petrol
- and, that petrol is a finite product that will at some point run out .

Women saw the move to hydrogen as necessary due finite nature of petrol and that an alternative was required. The female group particularly expressed the opinion that at some point a petrol alternative was required. This was expressed in a social context as a concern for their children.

"the fuels are going to run out, maybe not for 50 years but its going to happen, just think about your children."

"Its going to happen [running out of fuel] in their or their children's lifetime, I think that's just the scariest thing, like how the Arab world is with us now. I know you still need to use petrol but maybe you can use less, we don't know if they are going to say 'right you aren't going to have any more"

(both comments by women)

The main concerns with the move to hydrogen seemed initially to relate to the potential for the supply side of hydrogen to be monopolized by large corporations in the same was as petrol has been done to date this was a particular concern for the men. Yet in a dichotomy the groups also saw the involvement of the multi nationals as reassuring in being able to deliver a secure source of hydrogen fuel.

"if the oil companies or involved it gives you a little more reassurance that it is going to be there long term......."

Woman

"...the availability is an important factor."

Woman

It was also seen that there may be a political motivation i.e. reducing our oil dependency on the middle east.

"I am quite cynical about it [H2 fuel] Also, I think it has to do with where all the petrol and crude oil comes from, I think they want to cut as many links with the middle east as possible because any way of not buying crude oil from the middle east, we won't be putting money into these countries"

Man

3.8.5. Safety

The issue of safety again brought about a dichotomy of feelings between a general belief that new hydrogen technology would be required to be safe and the contrasting historic understanding of hydrogen being dangerous (with specific reference again to bombs and the Hindenburg) combined with an unease with the prospect of accidental leaks and explosion due to crashes. They did however look at the safety of hydrogen quite pragmatically, using petrol as a comparator.

"Working in the bus industry before, I know the testing the busses go through is rigorous, compared to a car it's another 50% again, if they have managed to get it into a bus it is going to be safe, because they do put them through rigorous testing."

Man

"As long as we were told it was safe and we knew how to manage it, and knew the do's and don'ts. I am sure those of us who do have our heads screwed on, they are going to be responsible."

Woman

"I don't think you can get away from the bomb because when you talk about hydrogen people will think of the hydrogen bomb."

Man

"I think I will be for it definitely because I don't think the Government will let it go ahead if it wasn't as safe as petrol."

Man

"Well they [the Government] *sponsored nuclear power development. I don't have that same faith in the Government."*

Man

"I don't think anything like that happens if it wasn't safe, because there are so many pressure groups."

Man

The all the female group assumed that the introduction of hydrogen would be accompanied by testing and training of all appropriate services and that previous historic occurrence were a null point.

"I think we've advanced a bit since then."

Woman [referring to the Hindenburg]

The male group initially had concerns with potential safety issues relating to accidental leaks and crashes, but developed a pragmatic discussion comparing hydrogen to petrol that was similar across both groups.

"Well you have got the issue of what happens when it goes into the environment and the crash issues but you have that with diesel and petrol cars now."

Man

"I was just thinking if they had had a discussion group about a combustion engine run on petrol, what would it be like, how dangerous it would be and how it could

explode, they would probably be saying very similar things to what we are saying now."

Man

"If you have a pot of petrol on the table you would be very nervous about it. When it's in your car and you get it from the pump you don't really think about it."

Woman

"Gas cylinders get transported around on the backs of lorries and they are under pressure, so I don't think I'd be that concerned."

Woman

3.8.6. Cost

There was a general consensus that cost would be a major influencing factor in the uptake of the technology, whether in the end use or the fuel itself and that any environmental benefits would be a secondary consideration even for those with an environmental conscience.

There was a debate as to how the technology could be introduced affordably with most deciding that government intervention would most likely be necessary to kick start the move. However, this was not necessarily seen as a positive method as there was a feeling that due to the temporary nature of the interventions it would be possible for governments to then take advantage by increasing the levy on hydrogen (currently 0%).

"I think it's more an issue with cost... I think if you went out to the streets and asked 2000 people, 70% of them would think of more of the cost than the environment. You are only thinking in the short term."

Woman

"They will probably make it cheaper and give people tax breaks for doing it."

Man

"They will wait till we are all addicted to it and put the taxes up."

Woman

"I mean, give it a couple of years and the government will get their claws into it and then it's not going to be cheap."

Man

The groups felt that there was not a willingness to pay for the added benefits of hydrogen over conventional fuel; none of the group members interviewed in the focus group were prepared to pay any extra fare to travel on a hydrogen bus as opposed to a traditionally fuelled bus.

3.8.7. Environment

The groups approached the environmental implications of hydrogen from different stances:

The women had a negative world view of the current environmental situation, with long term concerns and the hope that an alternative could bring about beneficial change. They were proactive in implementing changes in the home (recycling, fuel use reduction) but were also aware that large scale environmental change could introduce conflict (due to reluctance of uptake).

"We are so advanced in things more than before, but we are still using petrol, which is giving off things that are causing problems but by the time our children are having children I wonder what state we are going to be in. I hope we can find something that is better for the environment."

Woman

"Something that is renewable, our fear is we are seeing it in perhaps the weather changes and what we were supposed to see in perhaps 20 years time we are seeing now with the rain, we don't know how much that has got to do with the ozone."

Woman

"But it is a fear for my children I think."

Woman

"You seem to every day pick up a paper and see more situations classed as natural disasters but we don't know if that is why."

Woman

"I think the pollution side if they could prove it's better 'cos these days pollution is a big thing, with people who suffer from asthma."

Woman

"Just putting it [hydrogen fuel] *forward as an environmental thing isn't enough."*

Woman

The male respondents were generally less concerned and believe that there would be a shift from one pollutant to another.

"There are environmental issues with producing petrol and there will be with this [hydrogen] *too, the difference is it's going to be a different set of environmental issues. "*

Man

3.8.8. Hydrogen and Wales

On completion of the first day the facilitator informed the participants of the ongoing hydrogen projects in Wales. The facilitator also informed the groups of ongoing projects in the rest of the world. In each case neither group had prior knowledge of these projects or trials.

The knowledge that Wales was at the forefront of research in the area was a area of pride for both groups, and even though the previous and, in some cases, negative comments and worries about risks the groups both thought that it would be *"it would be great"* in terms of increased economic growth for Wales. There was a general feeling that it could be a potential for job growth and economic development and an opportunity for increased tourism.

"It would be exciting if Wales could produce it, whatever the method, so we could be self-sufficient, it would be a real boost for the economy.

Woman

"It will bring in more jobs, good politically, could raise the intellectually level of the country, could put us on the map."

Man

"It [hydrogen*] will be good because we could produce it ourselves."*

Women

3.9. Public Perception (session 2)

At the end of the first session A number of questions were outstanding these were the relayed to the expert (S.Paterson) to enable preparation of answers for the next session in order for the second session could progress into new ground, having had external stimulus.

The questions participants wanted the expert to respond to fell into general groups:

- Hydrogen as an element;
- Difference between using hydrogen internal combustion engines and fuel cells;
- Environmental impact of making and using hydrogen as a fuel source;
- Transport;
- Cost.

Specific questions posed to the expert included:

- How hot is the steam from a fuel cell car?

- How big are fuel cells?
- What happened when fuel cells run out?

3.9.1. Public perception

Specific questions were asked of the 'expert' (S.Paterson), these were answered and included visual references (see Appendix 8) and the results recorded in the table below.

Table 3.8. Session 2 questions

Specific Questions	**Participants Reponses**
How hot is the steam from a fuel cell car?	Participants were reassured that the steam would be lower than the *actual temperature of the exhausts at the moment.* Moreover, the hydrogen-fuelled buses have their exhausts on the roof so that the steam rises
How big are fuel cells?	Examples of cars with fuel cells were displayed
What happened when fuel cells run out?	The group seemed happy that it is possible to fill up on hydrogen (in the same way as petrol) and in learning that hydrogen does not have a 'shelf life' and can therefore act as an energy store was another point in its favor. The groups found this particularly reassuring if combined with renewable energy (wind)
Does hydrogen smell?	The expert informed the groups that although hydrogen gas does not smell, the health and safety executive would insists that the gas would have a smell added to it so that people can detect leaks. The women's group saw parallels with natural gas.

How safe is a hydrogen car in comparison with a 'normal' petrol car	This was demonstrated using photos of tests carried out by Dr. Michael R. Swain, University of Miami. The images and explanation of the experiment seemed to reassure both groups with one man commenting "I would rather be near the hydrogen car"

This lead on to some discussion relating to the safety of vehicles and a discussion on the relative risks involved with using a petrol car.

"I was thinking if they had had a discussion group about a combustion engine run on petrol, what would it be like, how dangerous it would be and how it could explode, they would be saying very similar things to what we are sating now."

Man

"And fuelling it up on their own with a nozzle, and they can wave it about, I think that's a potentially scary thing, I mean people go in there smoking, but people just get used to it."

Woman

3.9.2. Production methods

Production processes had not been brought up in the first session by either group within the first session, apart for in generic terms relating to large industry. So in order to facilitate discussion S.Paterson presented a brief synopsis of the types of production methods that could be used to produce hydrogen including images that can be seen in Appendix 8, The group were then able to incorporate the new information alongside their own experience and understanding of the issues involved.

The general consensus in both groups were that biological hydrogen production was a good route to pursue because it seemed to have little pollution associated with the wet processes.

"it would scare most people".

Woman

"Are we really moving forward if we are using nuclear?"

Woman

The fact that fossil fuel hydrogen plants produce hydrogen today reassured the group but they still linked these with regressive technologies.

When asked if they would accept hydrogen plants near them (renewable or otherwise). The women concluded that like any other development they would need reassurances regarding emissions and pollution threat. Whereas the men felt in addition to this that scale would be a deciding factor.

the production of by-products remained a concern in terms of its affect on the immediate surroundings. There was also a concern of the 'disposal ' or fate of the oxygen produced as a byproduct of some production methods.

"But what about the by-products from the factories that make the stuff?"

Man

"The by-product is water and it's the worst of all the greenhouse gases."

Man.

One concern for the groups was that any production processes that were used would in at least some way transfer the problems associated with vehicle pollution to the location of production.

"It just seems to transfer the problem to the place where it's being produced."

3.9.3. Usage

There was an overall expectation that the hydrogen vehicles would be akin to electric cars, in that they would be "like a milkfloat". Both women and men expect a high level of performance from their vehicle whatever the fuel source or they *"it would scare most people".*

Woman

"Are we really moving forward if we are using nuclear?"

Woman

The fact that fossil fuel hydrogen plants produce hydrogen today reassured the group but they still linked these with regressive technologies.

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"It just seems to transfer the problem to the place where it's being produced."

3.9.3. Usage

There was an overall expectation that the hydrogen vehicles would be akin to electric cars, in that they would be "like a milkfloat". Both women and men expect a high level of performance from their vehicle whatever the fuel source or they would *"never have entertained the idea"*. Therefore a manufacturer would need to meet these expectations to enable uptake of the technology.

The main feature in the decision-making process of the groups to use hydrogen, rather than petrol, was identified as:

- Cost (value for money, purchase and running costs);
- Reliability;
- No regular charging of parts;
- Distance limits.

"Basically they [cars] *have to last and they have to work."*

Man

Environmental consideration was not considered a priority by most participants.

Noise levels of hydrogen-powered vehicles were discussed as to whether noise levels would differ (be greater). When participants were informed of noise variations between internal combustion engine (ICE) and fuel cell they had no further concerns. Until raised, participants had not realized silent vehicles could be a problem (pedestrians not able to hear vehicles).

Women assumed transition to hydrogen power would be gradual, led by *"those who always have to have the latest thing"* and people would, through experience, have time to see that the fuel is safe and efficient before using it.

"The first thing I thought of is the explosion side of it but if people are using it and not afraid of using it…It's like anything new."

Woman

It was considered that public services, such as buses, needed to be used to generate publicity, helping to inform people about hydrogen and enable them *to "get used to it"*.

There was some suspicion from the men about the current focus on public transport. Questions were raised about whether this was a way to force cars off the road. In a similar vein, there were also concerns about forcing people to buy more expensive hydrogen fuelled cars, rather than having their existing car converted and that only newer cars would be able to be converted The men recognized that hydrogen fuel will not solve congestion problems and this left some room for suspicion that the government would still use the tax system to pressurize people off the road.

There was some a belief that:

"We will get forced in to it anyway and won't have much of a say in it."

Man

Women seemed to have a grasp on the Government's role in applying regulations relating to hydrogen production and use, whereas men saw the technology being market driven with politicians *"jump[ing] on bandwagons"*. Some felt that the scientific community needed to speak out in favour of hydrogen but others were sceptical of their involvement. There were also realizations that not everyone would be in favour of change.

"Why trust them so much? It was trumpeted that nuclear power was safe and battery powered cars would save the day but they ran into problems. They do that with all sorts of technologies."

Man

"Someone will set up a group to say they don't like it."

Man

The men also felt that another technology might come along and replace hydrogen in the not too distant future.

Participants identified some groups, such as the elderly, for whom change might be threatening or difficult. Moreover, they believed that educating children about hydrogen would be a good way of disseminating information and reassuring people, as children can be used to educate their parents.

4. Discussion

4.1. Biohydrogen

4.1.1 Methodology Considerations

The trial nature of the technology requires a number of assumptions which need to be validated in field trial conditions.

The data collected relating to crop yield and composition was taken from reliable trials and historic and recent data using standard farming practices [64, 66 -79] and is not specific to the dark fermentation process as used here. Once a trial plant is running it will be possible to obtain accurate running data and compare with the assumption that it will be similar to AD.

In addition to the aforementioned energy inputs there may be value in researching how change in climate conditions may change the crop growth inputs over the long term. This could result in the need to move to more drought hardy crops [105]. Further, under different climate regimes crops are likely to change composition [106]. On larger scale reactors it may be possible to increase the hydrogen yield of the feedstock closer to its upper theoretical limit.

In addition, research has lacked in assessing how the biohydrogen stage affects the methane yield stage, and this could be an area for further work.

4.1.2. Results discussion

Using the assumptions in Table 2.3. we can see that the most promising crops are, in ascending order, (highest net energy yielding):

- Sweet Sorghum (223,928 MJ yr ha^{-1}),
- Forage Maize (121,522 MJ yr ha^{-1})
- Sugar Beet (112,624 MJ yr ha^{-1}),
- Perennial Rye Grass (114,189 MJ yr ha^{-1})
- Fodder Beet (117,063 MJ yr ha^{-1}).

Sweet sorghum is on initial inspection the most likely candidate for hydrogen production. However, despite it being the largest net energy output, the crop itself has only a one month harvest window (Figure 3) with expected yields of 20-27 tonnes ha^{-1}. This large amount of feedstock would require an oversize of the reactor which would result in an under utilisation for the rest of the year. This in turn would likely drive up energy input (requiring heating of the much larger tank) and reduce the overall net energy output over the course of the year.

Sweet Sorghum it is not a proven crop in the UK it is currently at trials stage, and it is expected that farmers would be reluctant to commit to commercial growth.

Of the remaining crops, Fodder Beet and Sugar Beet are almost identical crops, (Sugar beet is a selectively bred form of fodder beet). Sugar beet is used in the food industry to produce sugar whilst the fodder beet is mainly used as an animal feed; both are harvested over 5 months and may be stored for several months (albeit with a conversion of circa 10% sugar to starch per month). As a result of the higher net energy output, Fodder beet was seen as the most promising candidate for dark fermentation from these two crops. Additionally, it does not compete directly with food production.

It is therefore concluded that the most appropriate crops are Forage Maize, Perennial Rye Grass and Fodder Beet. The Fodder Beet and Perennial Rye Grass have complimentary harvest windows, large net energy output and the yield of crop does not oversize the reactor.

However, as mentioned in the section above the need to consider potential impacts on crop composition due to climate change is needed.

If climate change were to bring about hotter drier winters this would lead to the reduction in sugar content of beets [107], lower dry matter content in forage maize, or the breaking of stems in extreme weather events [108] Perennial rye grass, however, is quite hardy and does not suffer from leaf death at above 33°c [109].

Across these crops the average energy ratio is 10.4% as H_2 and 89.6% as CH_4. However, Sugar Beet produces a higher ratio of H_2. If the system were designed around hydrogen production alone, and not overall energy output, sugar beet is the preferred crop. Research efforts are ongoing to improve hydrogen output of sugar beet and rye grass; additional research could be directed at improving this ratio for other crops.

Based on these figures, and assuming the allocation of 14640 ha set aside (Table 3.1.), it is calculated that Wales could produce 0.48 TWh of energy from dark fermentation processes.

This assumes the crops are divided equally between Forage Maize, Fodder Beet and Perennial Rye Grass, in order to accommodate crop rotation for energy production. It may be possible to increase this yield if crop rotation were modified to reduce energy inputs to the system or if a way of introducing Sweet Sorghum into the rotation were possible without having to oversize the reactor (e.g. by extending the harvest window).

0.48TWh equates to the ability to power 111,469 homes in Wales, assuming an average household consumption of 4,290KWh yr^{-1} [5] of electricity per year or around 9% of homes [110].

Alternatively, based on the assumption of an average annual UK car mileage of 11,000 miles and a fuel consumption rate of 8.9 litres/100 km of petrol, 0.48 TWh is the energy equivalent of sufficient fuel for circa 35,000 cars per annum.

The overall CO_2 emissions reduction from a change to bio-hydrogen is estimated to be over 114,768 tonnes per annum in Wales. The estimated reduction of CO_2 was calculated using the conversion efficiency of 0.24 Kg CO_2 KWh^{-1} [111], or around 10% of the welsh CO_2 reduction targets for 2010.

The estimated yields used in this paper were of mode harvest yields (therefore a conservative estimate) Set-aside is high quality land that would normally be under food cropping and thus it would be expected that these are routinely achievable yields.

The determining factor for the use of set aside land proposed here would be the outcome of a full economic comparison with other energy and non food crops

If 8% permanent grassland were used then the land available would rise by 76,760 ha, producing an estimated 2.9 TWh, and powering nearly half the homes in Wales. This would meet almost 75% of the 2010 energy reduction target for 2010, and 40% of its 2020 target. This is an optimistic scenario as the quality of the land would likely inhibit the yield of the crops.

The energy contribution of this technology could be considerably increased if food industry co-products, municipal solid waste, crops residues and crops growing on other agricultural land were used, however, this would require a change in legislation. But would reduce the amount of waste sent to landfill, and potentially meet recycling requirements of councils.

4.2. Public acceptance study

4.2.1. Methodology considerations

This is one of the first qualitative studies undertaken on hydrogen. In the past there have been a number of studies undertaken using quantitative methods, these are useful in gauging the peoples understanding of hydrogen using tightly defined criteria, but are limited in their ability to probe views and comprehension. For example to ask "how much do you understand about hydrogen" lots, a little, nothing tells us nothing about what they actually 'know', how they come to 'know' it or if indeed they may change their mind about 'knowing' it.

This study highlighted a number of anomalies between the quantitative and qualitative trials, and highlights a number of areas where the results correlate to published findings.

Despite the fact that this study was not statistically validated or structured, it has provided insight into the public attitude to hydrogen in Wales, and provides exploratory findings that can be used as a base for future work. Indeed this work has been followed up by Bellaby and others [37, 38, 39, 40].

4.2.2. Results discussion

The level of understanding of hydrogen was limited to the chemical nature of the gas and its properties. The groups' knowledge of hydrogen as a fuel vector in terms of a 'hydrogen economy' was limited to a passing awareness of a news report by only a few of the participants. This is consistent with other work in the field [37] [38] [39]. However this is not in itself a hindrance to people holding an opinion [41] as they bring their pre evolved opinions and experiences to the discussions and demonstrably used this prior knowledge of other situations to frame their opinion to this technology as would be expected by SI theory. Their predispositions to the environment and technology seem to have been a stronger influence than knowledge and they brought this into the wider contextualization of hydrogen technology in order to frame discussion and make value based judgments.

In general it was found that hydrogen and the hydrogen economy was not seen as a standalone issue and the groups raised a number of issues that were seen as key to the development of the hydrogen economy, these were; Safety, cost and environmental sustainability.

Safety was brought out as a concern by both groups. It was, however, not seen as a reason to stop the development of hydrogen. The groups were very pragmatic when dealing with the risk issues by comparing the uses of different fuels and using their own experiences of technology change (petrol to LPG conversion) in order to try and frame the risk perception. This was in line with the findings of Flynn, Bellaby and Ricci [37-39], who found a similar level of pragmatism.

Cost was seen as a major influencing factor to the success of a developing the hydrogen economy. It was perceived that if the marginal cost of the technology is greater than the existing technology then the uptake / adoption of the new technology would be limited. The groups did not see that the environmental benefits would sway the general public unless the consumer was inclined toward the purchase of the latest technology or there were some other added benefit. These findings concurred with findings by Bellaby, Schult and Ricci [32, 26, 33]. This is contrary to the with the findings of O'Garra [31] who suggested that taxi drivers were willing to pay a premium for the use of hydrogen vehicles. It is possible that this may be due to the perceived added marketability of the journey and subsequent tariff charged for a 'green' product, as suggested by Rösch [48].

A further issue that was seen as an important factor was the need for hydrogen production to be environmentally sustainable. The groups felt that the production of hydrogen from fossil fuels and nuclear were only transferring problems and environmental pollution to production sites.

The groups favoured the use of renewable and particularly biological production methods. It was seen by the groups (particularly the women) that the sustainability of energy and a move to carbon neutral /free technology would be a main driver as they expressed 'fear for the future' if the current status quo was continued.

The idea that Wales could become self-sufficient and a leader in this field aroused national pride. It will be interesting to discover if the findings of this study are transferable to the rest of the Wales, including rural and more bilingual areas. In particular, the rural/urban divide needs to be explored given the recognition that pollution could merely be displaced from the point of use (towns and cities) to the point of production (more rural areas).

The results of the attitudes for science indicate that there was a feeling of support for science and that the participants believed that regulation of science was being taken responsibly - This broadly mirrors the findings from the Office of Science and Technology and the Wellcome Trust [43]. The work by Tarigan [42] and Achterberg [41] suggests that this belief in science and technology may drive a more positive attitude to technological change, providing in combines with a strong belief and predisposition to environmental stewardship.

4.2.2.1. Influencing factors

It must be noted that the concerns expressed about security of supply was more than likely heightened by the wider context of the situation at the time; the Iraq conflict covered widely in the media (Television, Radio and Newspapers), the rising price of oil and utility prices, and against a backdrop in recent memory of the 'fuel crisis' (blockades of petrol refineries by protesters against tax increases) in the UK in the autumn of 2000.

4.2.2.2. Gender differences

It has been proposed that, because of the different priorities that men and women have in society, they could have different emphasis on environmental priorities.

"Because men and women are likely to have different roles in the family, community and work force, they are likely to have different personal priorities when it comes to environmental protection at the local and community level."

United Nations [112]

During the study some gender differences were apparent. Some of the men who took part in this project were very negative although this was not picked up in their belief in technology as seen in section 3.8.2. The women's group showed a greater concern for environmental issues and drew from experience using examples of weather phenomena as a proof of climate change. They also expressed concern for their families and future generations.

Both men and women had an established belief that said men would want to "*pull things apart and try to look for reasons* [to dismiss a technology]" and that "*women are more accepting* [of technology]". Women also thought "*men don't seem to accept change quite so easily.*" This directly contradicts the Schulte *et al.* [26] and LBST [28] studies that found that men were more accepting of hydrogen and hydrogen technology.

It should also be borne in mind that the men in the group had more knowledge of hydrogen as a chemical and Shaw [113] found that the better educated are more sceptical of scientific developments. However, Achterberg [41] states that, although increased knowledge can lead to a reduction in acceptance, that the persons predisposition to value the environment reverses this trend and a person with a belief that the environment needs to be cared for will in fact become more supportive of the technology with more knowledge. This may be the reason that the reversal in trend was found in the focus groups.

Both gender groups used their knowledge of previous situations to frame their views of hydrogen safety. But it was found that the men were more concerned about safety than the women. The men who were less concerned reassured the rest of their group about safety by referring to previous and current situations (such as the introduction of LP gas vehicles). The women more often identified with parallels that had gone well and this reassured them about hydrogen.

Participants did find the environmental argument to be reassuring and something that makes hydrogen worthy of consideration. Indeed, biological and renewable energy sources were seen as the most desirable ways forward for hydrogen production.

It was viewed by some, that:

"Most things work on a proof of a track record. So once the tests have been done and they have proved themselves, I think most people are going to go for it, it's all down to the way it's marketed."

Man

"it's like with anything, people need time to get used to it."

It is interesting to note that similar findings to the ones presented here were obtained by Bellaby *et al*, Ricci and Flynn [37-39]: a clear need for the technology to be cost effective was identified, safety was a concern and there was a need for clear information from trusted sources. The environmental advantage was not seen as sufficient cause to move to hydrogen energy

4.2.2.3. Age and social grade

The participants of this study were of a mixed demographic. A review of the demographics of each of the groups (male and female) shows they all fall within the 25-60 age range that are the most accepting of science and technology as discussed in section 1.6.

Within the breakdown of social grades in the focus groups, it was found that the male group's, social grades E, D, C1, B were represented in the ratios of 1:2:2:2 respectively. It was found that the male group had a slightly negative attitude towards hydrogen technology and some members of the group were very distrustful of authority. As discussed in section 1.6. It has been found that those in the lower social grades DE are more likely to be sceptical about science and technology, whereas those with a higher social grade were more likely to have a positive disposition. This goes against type in this study as there is a small bias toward the higher social grades within the groupings. However, due to the very small sample size it is inappropriate to draw wider conclusions from this as this result may be an artefact of one member of the focus group responding against type. A larger study, of an order of magnitude greater, would be required in order to derive a set of conclusions at a sufficient level of confidence, particularly as in some cases within this study a single person represents a particular social grade.

The female group had a higher proportion (n~6) of C1B social grade as opposed to only 3 C2D's. It was found that most of the women were very supportive of hydrogen technology and had a higher level of trust in authority than the male group. As noted above, due to the small sample size, it is difficult to draw out any conclusions in relation to social and educational standing, especially as it also relates to the individual's trust in authority. Further, any positive bias within the women's group would be tempered by the general reservations women hold regarding science and technology, which has been reported in literature [45] and may be due to differing social concerns relating to science and technology [58,43, 112].

Within this report we do see that women are more supportive of hydrogen technology, however due to the small sample size of social grades D,C1,C2, B (1:2:5:1) It would be difficult to ascertain what additional biasing effect this may have had on the outcome, as discussed in section 1.6. However, it is accepted that there may have been a small influence from these demographic factors in this study, which was conducted at a relatively early stage in the development of the hydrogen fuel debate.

4.3. Linking public perception and the biological hydrogen production reality

The results indicate that there is the potential for bio-hydrogen to meet almost 10% of Wales' energy reduction targets for 2010, or 40% of the 2020 target if permanent grassland were used. This technology would be energetically viable. Additionally, the public perception of biologically produced hydrogen in positive and is seen as a desirable in terms of its sustainable nature.

Bio hydrogen would address some of the supply issues, and concerns the groups had for monopolies developing in hydrogen production, as the technology would be both widely distributed in rural areas, and linked to agricultural production leading to agricultural diversification.

The groups felt that biological production methods would have the least environmental impact. The use of crops as a feedstock could address the main concern of the groups that polluting by-products would be transferred to the production sites. The effluent of this production method, providing the crops are grown on the farm, is able to be used as a fertiliser on the land, thus the process would have a low environmental impact. If 'wastes' were introduced to the feedstock stream this may reverse as it may change their opinion of the technologies 'green' image. It would also cause problems as unless the added streams were fully traceable then it would not be able to be used as fertilizer.

A significant factor that the groups raised was cost and the possibility of financial incentives being needed to encourage and support people to move to hydrogen energy sources. Participants suggested tax reductions on cars and fuel and grants for converting domestic boilers. At present hydrogen attracts a 0% Government tax rate, so the process of incentivisation has begun. It is far from clear what the future of the energy market will be and section 1.2 indicates that there are a range of suggested prices for bio hydrogen, if expected targets are achieved then the use as a transport fuel would be economical.

Based on the initial focus group research, the biggest issues related to the future of hydrogen fuel are mainly related to production, safety at the point of use, cost and performance against the alternatives. As some participants were sceptical of politicians and others were sceptical of scientists, a recommendation that a spread of experts is used providing a consensus can be reached across this diverse set of groups. Finally, given the major focus of the participants on the costs of hydrogen based technology, cost considerations must investigated, including tax breaks and any incentivisation that may be required.

Any project that sets out to engage the public with hydrogen fuel must provide information about the cost, safety and production of the fuel. In addition, all dialogue/communication activities to engage with the public must use illustrations, since visuals made a clear impact on views in the group sessions.

5. Conclusions

The main conclusion of the study is that it is energy favourable to undertake the conversion of crops to hydrogen together with biomethane production on a farm scale, providing the appropriate crops are used along with the most energetically favourable methods of farming and conversion. This would (based on the small scale public perception study carried out) be favourable to the public and meet with their pre existing expectation that biologically produced hydrogen is better for the environment than fossil fuel produced hydrogen and that decentralisation could be a positive outcome. Making biohydrogen from dark fermentation a valid and viable (in terms of positive overall energy output and public perception) option for future pursuance and research.

The positive net energy output of agriculturally based hydrogen production using dark fermentation technology, to meet both rural power and transport applications, has been proven. Sugar beet, forage maize, fodder beet and perennial rye grass were found to be the most appropriate energy crops to grow, with the net energy output being 112,624 MJ yr ha^{-1}, 121,522 MJ yr ha^{-1}, 117,063 MJ yr ha^{-1} and 114,189 MJ ha^{-1} of fermentative hydrogen and methane production respectively. These crops would provide feed for the process over ten months, allowing both constant throughput of the reactor and a smaller reactor size and, hence, a more energy-efficient production process.

Sweet sorghum has a potentially high energy output of 223,928 MJ yr ha^{-1} but is unlikely to be adopted in the short term either commercially or for the purpose of the generation of hydrogen as it is an unproven crop.

The use of 114,189 ha land in Wales could provide 0.47 TWh of net energy, 10.4% as H_2 and 89.6% as CH_4. This would correspond to savings in emissions in the order of 114,768 tonnes of CO_2 per annum and contribute to 10% of the 2010 target for carbon dioxide reduction in Wales.

The main concerns of the public were safety (both of use and in production) and cost. Cost remained paramount, even in the light of environmental considerations.

The groups' attitude to the development of hydrogen technology was supportive but with the caveat that price and safety should not be compromised.

The groups took an overall view of hydrogen technology, discussions were diverse and although the participant's knowledge was low they drew on their personal experiences and predispositions in order to form opinions and make decisions.

There appear to be no barriers in terms of public perception or potential energy yield to the introduction of agriculturally based hydrogen production as energy output is large enough to make a difference to the Welsh energy economy whilst public perception seems positive, with this type of technology being preferred, providing it can be proved to be economical and safe.

However, unless the technology is cost effective, in fact more cost effective than current technologies, participants would be reluctant to shift to hydrogen technology. Whether the results would differ, in the current economic climate, specifically in light of the increase in petrol and utility prices, needs to be investigated. Even in light of environmental considerations cost was of paramount importance. Hence, environmental arguments alone seem unlikely to change fuel usage behaviour.

6. Recommendations

Before any major campaign in hydrogen technology is undertaken in Wales, further research is required. Additional research should be focused on both a qualitative and quantitative assessment of Welsh public perception of hydrogen technology and its associated applications. This work should be informed by the work of Ricci *et al* [33] and use a statistically valid sample size. Further, it would be advantageous to interpret the results of this work in light of the work of Achterberg *et al* [41] who identified the cultural attitudes to the environment and technology

Any public perception work in Wales should include representation from rural Wales and Welsh speaking citizens, alongside significant urban groupings, to confirm whether any geographical and cultural differences exist within the Welsh population. It would also be advantageous to include data on educational background of the participants as this is known to have an impact on acceptance of new technologies. In any future study I would recommend that the groups were recorded using audio visual equipment so that individuals could be identified and further analysis undertaken.

A further recommendation would be to ensure contractual requirements are specific and should include transcripts of raw data.

Cost implications of the introduction of the technology need to be investigated, with particular reference to the production and distribution costs and, ideally, a study into the types of incentivisation that could be pursued.

Finally, energy potential for household and industrial food waste needs to be investigated in order to understand the full potential of this technology.

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Appendix 1 – An exploratory study of public opinions on the use of hydrogen energy in Wales

Public attitudes towards the use of hydrogen energy in Wales

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Abstract

The introduction of hydrogen into the energy market is being pursued by governments around the world in an effort to abate climate change, provide security of supply and reduce air pollution. While technological aspects are well researched, the social aspects of the transition are not. The public's attitude and perception of hydrogen energy will be of great importance as we move closer to the implementation of the technologies. Using two focus groups, Welsh public attitudes to the production and end use of hydrogen energy were studied. Gender differences were apparent, as women were generally more accepting of hydrogen technology. The main concerns were safety (both of use and in production) and cost. Cost remained paramount, even in the light of environmental considerations. The groups' attitude to the development of hydrogen technology was supportive but with the caveat that price and safety should not be compromised.

Keywords: Hydrogen; Public attitude; Hydrogen technology; Acceptance; Wales

1. Introduction

Concerns over the environment and security of supply are driving governments towards the development of a hydrogen economy. The UK Prime Mister Tony Blair (2004) has recently said of climate change "···unabated it will result in catastrophic consequences for our world". The third assessment report of Working Group 1 of the Intergovernmental Panel on Climate Change (IPCC, 2001) has estimated that global climate temperature will rise by 0.2°C per decade. Emissions of CO_2 and other gases are the dominant influence on climate change. The UK government has signed up to the Kyoto treaty which commits the UK to reduce its carbon dioxide emissions by 12.5% below 1990 levels by 2010. The government has adopted the Royal Commission on Environmental Pollution's suggestion that 60% reduction in carbon dioxide is needed by 2050 against 1990 levels (RCEP, 2000). The recent UK government White Paper (DTI, 2004) has identified hydrogen as a tool for reaching these targets.

Hydrogen is a clean fuel with no CO_2 emissions and can be sustainably produced through CO_2-neutral processes. It is increasingly seen as a key solution to the energy problems of the 21st century, providing clean and efficient heat and power from a range of indigenous sources. Like electricity, hydrogen is an energy carrier requiring an energy input for its production. Hydrogen can be produced and used locally to generate electricity or used as a fuel for vehicles. It has the potential to benefit all sectors of the economy as a replacement for petroleum fuels. To ensure that these benefits are achieved in full, it is important that the hydrogen is produced from renewable energy sources. Hydrogen storage brings the added advantage of overcoming the intermittency associated with renewable energy sources by allowing the storage of energy over long periods, for use during peak energy demand. The current state of hydrogen technologies and associated economics has been reviewed by Cherryman *et al.* (2004).

However whilst we must accept the global nature of a transition to a hydrogen economy we must also realize that it will develop under the specific political framework of each country and reflect the cultural differences of peoples. In 1999 Wales became a devolved government through the National Assembly for Wales. Section 121 of the Government of Wales Act 1998 obligated the Welsh Government to pursue sustainable development through all aspects of its work. This puts Wales in a unique position as one of the first countries legally obliged to take decisions based on sustainability. In support of this policy guidelines on renewable energy have been developed (NAfW, 2002 and 2004) in a call to make Wales a renewable energy showcase. Despite this admirable desire to trail-blaze the development of sustainable solutions and carbon abatement, there has at times been a backlash from the public against developments that fall in line with this legislation, particularly wind farm projects being developed on the coast. Thus engagement with the public is paramount in order to ameliorate concerns.

In other countries the development of the hydrogen economy is occurring for different reasons. Technology development is occurring in California due to zero emission legislation which requires a percentage of all new vehicles sold to be emission free. Iceland has committed to becoming a hydrogen economy by 2050 to make use of abundant hydro and geothermal energy and eliminate dependency on imported fossil fuels. Development of niche markets has begun around the world in order to fulfill specific needs within the market place. The use of hydrogen fuel cells has been taken up by hospitals as emergency back up power and for a number of military applications including submarine use. However, in order for the technology to bridge the gap between niche market and mass market the general public will have to want to buy the technology. This leads to a dichotomy - how can the general public want a product with little or no knowledge of its existence? It has been argued by Shulte et al. (2004) that there needs to be a campaign to raise awareness of hydrogen and hydrogen technology before products come to market in order to ameliorate public concerns. In recent years hydrogen technology has been more visible to the public through media reports, whilst oil companies and car manufacturers have attempted to introduce the public to the new product ' hydrogen' through advertisements. However, no coordinated effort has been made in the UK to provide the public with a coherent awareness campaign. It can be argued that no such effort can be made until the public view of hydrogen energy is understood.

Limited studies have been conducted on public perception and acceptance of hydrogen. The Accepth2 Public Acceptance of Hydrogen Transport Technologies European funded project has been active in making an initial assessment of public attitudes in Germany surrounding the introduction of hydrogen buses. Two separate reports were produced on hydrogen perception as part of the project carried out by LBST (1998 and 2003). The reports are written in German and can only be accessed in English in synopsis.

Their first report (LBST, 1998) involved a three part study of attitudes towards hydrogen with students in schools and hydrogen bus passengers in Germany and a comparative evaluation of both sets of results. Part 1 of the study was carried out among 410 school students. It found that although acceptance was high, this was restricted to some degree if the technology was introduced with higher costs. This group acknowledged the explosive risk of hydrogen but did not see this as a barrier to introduction. There was a very small deviation in acceptability between genders, with girls being marginally less accepting of the technology, despite both gender groups showing a very low scientific and technical knowledge. The initial association with hydrogen was as a chemical or indirect chemical linking - there was no indication of environmental association.

Part 2 of the study was carried out among passengers riding the hydrogen bus (no numbers are given). It found this group accepted the technology without reserve, and associated the technology with environmental benefit. Association with danger was a secondary result, with connections to the hydrogen bomb and a very small proportion (0.1%) linked hydrogen with either the Hindenburg or zeppelins. The conclusions were that both the school students and the bus passengers had a high acceptance level of hydrogen and the technology, and understood the risk of explosion. However, there was no appreciable link with disasters.

The competitive evaluation (Part 3) found that knowledge (technical/scientific) of hydrogen or of the technology does not influence the acceptability of hydrogen and there is a general interest in learning more. Learning in school had a positive affect on acceptance; it is also suggested that demonstration of the technology could aid acceptance by the general public.

The Accepth2 report (LBST, 2003) gives analysis and comparison of eight studies carried out in German cities, which include the technical, political and social dimensions of hydrogen. The Technical University of Berlin conducted the first of the studies examined in 1998; it investigated hydrogen vehicles and their ambience. The study was conducted in Berlin at six public locations, where 150 people were randomly selected. The study showed that there was an overall positive response to hydrogen vehicles; the main concerns of the group were vehicle and fuel cost (36%) and performance and consumption (16%), the latter again relating to cost.

Another study reviewed by the LBST (2003) paper entitled 'The acceptance of hydrogen vehicles - on the use of new and novel fuel' was commissioned by the BMW group in Munich in 2000 when 1000 employees of BMW were interviewed. It found that the acceptance of hydrogen technology was high, particularly in male employees. The study concluded that general acceptance of hydrogen technology needs to be fostered and that trust and knowledge is needed in order to penetrate the mass market.

The LBST report (2003) also reviewed a survey of 156 passengers of the MAN fuel cell bus in Nuremburg in 2001, concluding that the passengers strongly supported the bus due to its low noise and pollution levels and were willing to tolerate moderate ticket increases to support the introduction. This was in spite of the passengers' low technical knowledge (9 out of 10 had no idea how the fuel cell worked).

Another interesting study investigated the factors influencing the market success of vehicles powered by hydrogen. Two surveys were conducted, interviews with high/middle management and internet interviews (LBST, 2003). This report found a generally positive attitude to hydrogen as a fuel with only limited concern over safety. The study found an overall high environmental awareness, which seemed to influence the attitude of the groups more than their technical knowledge (self graded as low/medium). It was seen that levels of education, car ownership and self-teaching were influential factors and gender had no influence.

To date in the UK only three studies have been published in relation to public understanding/perception or awareness of hydrogen. These were carried out in London. The study of Mourato et al. (2004) on London's black cab drivers found that environmental considerations affected taxi drivers' long term purchasing decisions. Schulte et al. (2004) focused their study on creating a model for hydrogen acceptance. Although not an acceptance study, it provides interesting background and insight into the development of people's perceptions and develops a model where areas of influence are highlighted. It shows that one of the easiest ways to influence perception of hydrogen is through product exposure, thus engendering a trust in the technology.

The most recent work to date has been carried out by O'Garra et al. (2005) who analyzed awareness and acceptability of hydrogen vehicles in London. This is the first study that has a statistically valid group; all other studies having been conducted using convenient subject groups. The study found that less than half of respondents had heard of hydrogen as a transport fuel and concluded that the safety worries of the respondents were not as high as they had expected with only 20% associating hydrogen with safety concerns. It may be noteworthy that this study was conducted prior to the introduction of the CUTE hydrogen buses to London. The majority of those people who did support the introduction of hydrogen vehicles had some prior knowledge, a factor which has been highlighted by other studies, including LBST (2003). The study also established that gender had a large influence on the acceptability of the technology with men being more supportive than the women questioned. The idea that there are gender differences between acceptability challenges the German LBST study (1998, 2003 in Berlin and Munich respectively) which found no link between gender and support. The different findings could be due to cultural differences between the three European cities. The O'Garra et al. study concludes that there is a need for more information to be made available to the public, as up to 60% of the respondents indicated that they needed more information before making a decision. In order to facilitate the transition to a hydrogen economy it is important that positive information is available on hydrogen, as attitudes are easier to form than to change. It is clear that there is a significant challenge to confront in terms of public information provision and public acceptance before the widespread adoption of hydrogen energy can take place (Goltzov and Veziroglu, 2001).

So far within Wales no work has been carried out on the public acceptance or awareness of hydrogen technology. The work reported here forms part of a study on the implications of a move towards the hydrogen economy in Wales (Cherryman et al., 2004). It is a first step towards establishing social attitudes to the use of hydrogen energy in Wales and towards the development of an appropriate awareness programme.

2. The study

This work was carried out as part of an EU-supported project – A sustainable energy supply for Wales: towards the hydrogen economy (www.h2wales.org.uk). The study was undertaken to understand public perception of hydrogen fuel and to determine the level of acceptability of hydrogen fuel technologies.

The study was carried out in October 2004 in 2 two-hour slots involving16 individuals:

Group 1: seven men aged 25-55, mixed social grade

Group 2: nine women aged 25-55, mixed social grade

The participants lived in South East Wales a region with 60% of Wales's 3 million population. Participants were recruited using a market research recruitment firm; a structured questionnaire was developed and distributed to the recruitment firm to ensure a spread of participants. Members of environmental groups, the energy industry and the media were excluded from the study as being more likely to hold strong views that may not be typical of the lay public. Participants were paid £60GBP by the recruitment firm to participate in the study. The venue, a mid-range hotel, was chosen to be neutral and non-threatening. The groups were separated by gender as it has been noted that women can feel intimidated by men in group situations, and can feel reluctance to discuss technological/scientific subjects. In addition, it may be expected that men and women have different priorities and concerns in relation to technical and scientific issues as discussed in Science and the Public (2000) and Eurobarometer *55.2* (2001). This gender grouping, together with the socio-economic and age ranges, provides a broad view of perception among the population in South East Wales.

In the first sessions the groups were led by a facilitator, who provided the Office of Science and Technology briefing notes on the hydrogen economy with some basic information (Postnote, 2002) as well as some more general information from the University of Glamorgan.

The facilitator stimulated the group with some general questions and the group was then allowed to continue to talk with the facilitator probing on relevant issues as they were raised, until the arguments were exhausted. This method allowed the study to draw out the complex picture associated with the image and perception of hydrogen and hydrogen technology. The end of the first session was used to gather questions to be answered by an expert at the second sessions.

The second session was structured around answering the questions raised by the group the previous week, which the expert did, aided by a selection of photographs. The session format allowed participants to ask new questions, raise new issues and reflect on and debate the information provided and previous discussions in their own way.

3. The groups' understanding of science and the environment

At the beginning of the second session the participants completed a self-assessment questionnaire to provide information on their attitudes to science and the environment. The questions were taken from *"Science and the Public: a review of science communication and public attitudes to science in Britain"* (Office of Science and Technology and the Wellcome Trust, 2000).

Through the questionnaire, it was found that participants were generally supportive of science. None agreed with the statement "I am not interested in science and I don't see why I should be" and only one woman disagreed that "science and technology are making our lives healthier, easier and more comfortable". There was also considerable trust in the regulation of science, with only one woman agreeing "the speed of development in science and technology cannot be properly controlled by the Government". This broadly mirrors the findings from the Office of Science and Technology and the Wellcome Trust (2000).

4. Session 1: The groups' understanding of hydrogen

At the beginning of the first session the participants' understanding of hydrogen was ascertained. In general, the women were less concerned than men at the mention of the word 'hydrogen', although for at least some individuals in both groups the word 'hydrogen' conjured up images of explosions. For women this was a response to gases in general, for the men it related to the hydrogen bomb and the Hindenburg accident. One of the women was a hairdresser and she associated hydrogen with hydrogen peroxide.

Everyone was aware that water is made up of hydrogen and oxygen (H_2O). The men, however, appeared to know more about hydrogen as a chemical, or at least they were more prepared to proffer information than the women. One man had heard of fuel cells in relation to hydrogen and one of the women had seen something in a newspaper about hydrogen being used as a fuel for transport.

Using a mock headline in a local paper announcing hydrogen-fuelled buses in Cardiff, the capital city of Wales, elicited knowledge from some about noise levels. Some were aware that cars and buses running on hydrogen (fuel cells) would be quieter than standard vehicles. In general, participants did not expect hydrogen-powered buses to look any different from 'normal' buses. While they did not see why such a bus would need to look any different, they also felt that the manufacturers would not want them to look any different. Moreover, several participants in both groups knew people who had converted their cars to run on Liquid Petroleum (LP) gas, and these did not look any different.

There was also some awareness that hydrogen powered buses would be cleaner in environmental terms because hydrogen is a clean fuel and that the only emission would be water/steam.

"It is a clean fuel."

"The only emission is water and there is an abundant supply of hydrogen." Men

However, there were instances where a little knowledge led to more confusion than clarity. For example, one man knew that water is H_2O, which led him to ask:

> *"If there is more hydrogen in the air won't that combine with the oxygen and produce water?"*

This, plus the fact that water is the main emission, stimulated a discussion about the impact of emissions on the local climate and whether it would rain more. Importantly, there was some confusion with helium, which probably stems from the similarity of the (unfamiliar) words and the use of both gases in airships.

4.1. Supply

The wider context against which discussions took place should be borne in mind. Just before the first sessions, there had been coverage in the media of the Venezuelan presidential vote and concerns about the future supply of oil from Venezuela. Obviously, the situation in Iraq was well known and the rising price of oil was featuring on national news. Several aspects of power and fuel supply were identified by the groups. Firstly, there was the issue of the security of supply of oil and the level of world reserves. Secondly, there were issues related to consumers being able to access retail outlets for hydrogen.

Participants were aware of problems in the supply of petrol and the women highlighted our dependence on petrol as a society by citing the problems caused by the 'fuel crisis' (blockades of petrol refineries by protesters against tax increases) in the UK in the autumn of 2000. Participants had a general knowledge that petrol would not last forever and that other sources of fuel are needed but were unsure of the timescales involved. The men raised the question of who would supply hydrogen to the consumer. Their first thoughts were gas companies such as British Gas, whom they assumed would monopolize the market. Once participants were aware that the big oil companies, such as BP and Shell, are involved in the development of hydrogen as a fuel source they realized how little they knew about the supply of oil. The involvement of these *"big concerns"* in the research reassured them. Weaning people off their cars was seen to be very difficult to achieve, so finding alternative fuel sources was thought to be very important.

"..the car is so convenient, so many people just jump in the car for the slightest thing." Woman

If hydrogen is to be used as a major fuel source, consumers must have easy access to reliable sources or they will not use it.

"...the availability is an important factor." Woman

As mentioned above, some participants knew people who had converted their cars to LP gas, especially taxis drivers. This was now a more feasible option as not only was it cheaper, but:

"You can get it [LP gas] at *Asda [supermarket] now."* Woman

4.2. Safety

There were two main views on safety. Firstly, there were those who believed that before anything was put on the market it would be heavily tested and therefore safe.

"Working in the bus industry before, I know the testing the buses go through is rigorous, compared to a car it's another 50% again, if they have managed to get it into a bus it is going to be safe, because they do put them though rigorous testing." Man

"As long as we were told it was safe and we knew how to manage it, and knew the do's and don'ts. I am sure those of us who do have our heads screwed on, they are going to be responsible." Woman

Secondly, there were those who were concerned about flammability and explosions, no matter what testing occurred, and the latter was cited in association with the hydrogen bomb.

"I don't think you can get away from the bomb because when you talk about hydrogen people will think of the hydrogen bomb." Man

Perhaps because of the awareness that hydrogen is *"highly"* flammable, there was greater concern in the men's group about safety than in the women's group. The men's group also raised the question of what would happen if there was a crash where there was an escape of hydrogen and how this would affect the atmosphere. There was, however, an appreciation that an accidental release of any type of fuel has implications.

"Well you have got the issue of what happens when it goes into the environment and the crash issues but you have that with diesel and petrol cars now." Man

Those who were less concerned about safety cited strong parallels with the dangers inherent in using petrol.

"I was just thinking if they had had a discussion group about a combustion engine run on petrol, what would it be like, how dangerous it would be and how it could explode, they would probably be saying very similar things to what we are saying now." Man

"If you have a pot of petrol on the table you would be very nervous about it. When it's in your car and you get it from the pump you don't really think about it." Woman

Some of the men were concerned about moving hydrogen around but others again identified parallels with existing technologies.

"Gas cylinders get transported around on the backs of lorries and they are under pressure, so I don't think I'd be that concerned." Woman

While some of the men considered the impact of accidents during transportation, the women assumed that the fire brigade would be trained to deal with accidents.

While the Hindenburg disaster sounded a note of caution for some of the men, the women's view was:

"I think we've advanced a bit since then." Woman

In conclusion, some participants believed:

"I think I will be for it definitely because I don't think the Government will let it go ahead if it wasn't as safe as petrol." Man

On the other hand:

"Well they [the Government] *sponsored nuclear power development. I don't have that same faith in the Government."* Man

But then again:

"I don't think anything like that happens if it wasn't safe, because there are so many pressure groups." Man

4.3. Cost

Cost was the primary consideration for participants when considering whether they would choose hydrogen as a fuel source personally. This was not only the cost of the hydrogen itself but also the cost of buying or converting machinery (such as cars or heating boilers) to run on hydrogen. Even for those more environmentally aware, cost was ultimately more important than the impact on the environment.

"I think it's more an issue with cost... I think if you went out to the streets and asked 2000 people, 70% of them would think of more of the cost than the environment. You are only thinking in the short term." Woman

Grants for conversion of appliances, homes and cars were suggested by the group, if the government wants to get people to switch to hydrogen. However, there was skepticism that once most people had converted, initially low prices for hydrogen would rise as a result of increased taxes.

"They will probably make it cheaper and give people tax breaks for doing it." Man

"They will wait till we are all addicted to it and put the taxes up." Woman

"I mean, give it a couple of years and the government will get their claws into it and then it's not going to be cheap." Man

With respect to public transport, participants said that they would not use a hydrogen bus if it was more expensive than a standard bus, unless it was raining.

4.4. Environment

The women believed recent changes in the local weather conditions, such as the exceptionally hot summer of 2003 and heavy rainfall in 2004, to be demonstrations of global climate change, as the following discussion illustrates.

"We are so advanced in things more than before, but we are still using petrol, which is giving off things that are causing problems but by the time our children are having children I wonder what state we are going to be in. I hope we can find something that is better for the environment."

"Something that is renewable, our fear is we are seeing it in perhaps the weather changes and what we were supposed to see in perhaps 20 years time we are seeing now with the rain, we don't know how much that has got to do with the ozone."

"But it is a fear for my children I think."

"You seem to every day pick up a paper and see more situations classed as natural disasters but we don't know if that is why."

Women also recognized that there could be benefits from a fuel that does not produce noxious fumes.

"I think the pollution side if they could prove it's better 'cos these days pollution is a big thing, with people who suffer from asthma."

The men saw the environmental issues as:

"There are environmental issues with producing petrol and there will be with this [hydrogen] *too, the difference is it's going to be a different set of environmental issues.*

The women were aware that everyone should *'do their bit'* with recycling and fuel conservation but they were also aware that this was difficult. It required some level of effort (such as taking things for recycling), some institutional changes (more facilities and incentives for recycling) and might even produce conflict with children (by, for example, limiting the number of televisions in a household). Hence, they believed that:

"Just putting it [hydrogen fuel] *forward as an environmental thing isn't enough."*

Despite this environmental awareness, cost remained the major obstacle in these participants' willingness to take up the technology.

4.5. Hydrogen and Wales

At the end of the first session, participants were informed by the facilitator about current hydrogen projects in Wales. All were surprised, none was aware that hydrogen is being produced and used in Wales. Neither was there awareness that bus trials are taking place in a number of cities around the world, including London. Participants were asked how they felt about Wales being at the forefront of the development of hydrogen technology. Even those who were more concerned about safety issues thought, *"it would be great"*. Participants thought that it would be good for tourism and for jobs.

"It would be exciting if Wales could produce it, whatever the method, so we could be self-sufficient, it would be a real boost for the economy. Woman

"It will bring in more jobs, good politically, could raise the intellectually level of the country, could put us on the map." Man

"It [hydrogen] *will be good because we could produce it ourselves.*" Women

5. Submitted questions

At the end of the first session the facilitator identified a number of questions drawn out from the discussions. These were relayed to the expert to enable her to prepare answers for the next session. The questions participants wanted the expert to respond to fell into groups: there were some technical questions about hydrogen as an element and the difference between using hydrogen to power internal combustion engines and the use of fuel cells; questions about the environmental impact of making and using hydrogen as a fuel source; questions about transport and questions about the cost. Specific questions posed to the expert included: how hot is the steam from a fuel cell car? how big are fuel cells? Both groups wanted to know what happened when fuel cells run out and how fuel cells are disposed of or recharged.

The expert gathered a selection of pictures and information to answer the concerns of the discussion group.

6. Session 2

6.1. Emissions

The heat of the steam emitted from hydrogen powered engines was queried with the expert but participants were reassured when they learned from the expert that the steam would be *"at the same temperature as the steam coming out of a kettle but the actual temperature of the exhausts at the moment is a lot hotter than that"*. Moreover, the hydrogen-fuelled buses have their exhausts on the roof so that the steam rises and this could be seen in the picture of the London bus passed to the participants.

6.2. Production methods

Although during the first session production methods were examined and information provided (Postnote, 2002) during the second session the issue was investigated further. Once the production methods were explained by the expert participants recognized that pollution would be removed from the point of use to the point of production. But the group did not have enough understanding of the processes involved to distinguish between the type of pollution produced by renewable and non renewable methods, as can be demonstrated by the comment below:

"It just seems to transfer the problem to the place where it's being produced." Woman

The most favored method of production was the biological methods involving algae and bacteria as these were thought to produce the lowest levels of pollutants. Participants, especially the women, thought that this line of research should be pursued.

"They use penicillin that came from mould in the first place. Although it sounds terrible, the end product is worth it." Woman

"We have to move on, so we have to realize that more money has to go into research" Woman

Production methods that are carbon neutral were more attractive to participants than those that relied on conventional fossil fuel electricity production. There were some concerns about whether sufficient trees could be grown quickly enough, as not everyone immediately grasped the concept of coppicing.

"As long as for the wood they are burning they can reproduce it, they need to make sure the on-going tree planting continues to outweigh..." Woman

There were also concerns that:

"You still have the burning though." Woman

The participants did not seem to be aware that CO_2 from biomass is part of the normal carbon cycle, unlike fossil fuel burning which will take millions of years to recapture the carbon.

Sequestering the carbon dioxide produced during hydrogen production was thought to be an option to be considered because scientists may develop a way of dealing with it in the future.

"We would hope the brains would move on and find another way forward." Woman

Using renewable energy methods, such as wind farms, to produce hydrogen was also seen to be a good way forward.

The expert wanted to explore how participants felt about using nuclear power to produce hydrogen. Participants were not happy with a nuclear power option. Not only was it seen as unsafe, it was seen as an old technology.

"Are we really moving forward if we are using nuclear?" Woman

Another woman felt that she did not know enough about nuclear power to comment and that she did not want to know more about nuclear power because *"it would scare most people"*. Nuclear power was not seen as environmentally friendly, unlike the renewable energy and biological production methods that had been described.

With respect to the location of production plants, participants said that if there was a proposal to locate a site near to their home they would want to know about emissions, safety, etc. just as with any other production plant. The women in particular saw nothing different about a hydrogen production plant from other industrial development. Some of the men, on the other hand, were concerned about the scale of the production plants, the sources of energy the plants would require and local pollution problems emanating from the plants. Questions were asked about whether the production of water as a by-product would mean that the local atmosphere would be damper than it might otherwise be.

"But what about the by-products from the factories that make the stuff?" Man

One man was concerned about what would happen to the oxygen left over from removing hydrogen from water. The expert reassured him that when used to produce energy hydrogen would recombine with oxygen, thereby keeping a cycle going.

One participant however, considered that:

"The by-product is water and it's the worst of all the greenhouse gases." Man

On learning that industry already produces hydrogen, and that initial production would centre on existing sites using existing methods, participants appeared reassured about safety and pollution during production.

6.3. Storage

Learning that hydrogen does not have a 'shelf life' and can therefore act as an energy store was another point in its favor. This was especially true in the context of using wind power to produce energy that could be stored for periods when there was no wind.

6.4. Usage

Some participants were surprised to learn that there are buses running using hydrogen fuel and that the car industry has long-term research projects in the area. Some assumed that performance would be like traditional electric cars, little different from milk floats. Performance is important to women as well as men. The women said that they would expect the same performance or car manufacturers would *"never have entertained the idea"*.

We asked participants what they consider when buying a car, as a way of eliciting how the use of hydrogen rather than petrol might feature in their decision-making process. Cost (value for money, purchase and running costs) and reliability were the two most important factors. Nothing that needs regular charging or has distance limits would sell to these groups.

"Basically they [cars] *have to last and they have to work."* Man

These participants acknowledged that some people would consider environmental performance but not the majority.

Questions were asked about noise levels of hydrogen-powered vehicles. Once it was explained that if hydrogen fuel were used to power an internal combustion engine noise levels would be the same as at present but with fuel cell technology noise levels would be reduced, participants had no further concerns. The expert who attended the second session raised safety concerns that had been voiced elsewhere about pedestrians being at risk if they could not hear vehicles coming. Participants realized this could be an issue but had not thought of it.

The women assumed that the change over to hydrogen power would be a gradual process, led by *"those who always have to have the latest thing"* and that people would have time to see that the fuel is safe and efficient before using it.

> *"The first thing I thought of is the explosion side of it but if people are using it and not afraid of using it...It's like anything new."* Woman

They thought that using public services, such as buses, to generate publicity would help to inform people about hydrogen and enable them to get used to it. They also believed that financial incentives would be needed to encourage and support people to move to hydrogen energy sources. Hence, they identified the need for a lead from Government. They suggested tax reductions on cars and fuel and grants for converting domestic boilers. Again, they found parallels in moving people on to condensing boilers, the introduction of natural gas and the switching of television from analogue to digital in the UK. They also suggested putting hydrogen-powered boilers into new homes and making new cars run on hydrogen.

Participants identified some groups, such as the elderly, for whom change might be threatening or difficult. Moreover, they believed that educating children about hydrogen would be a good way of disseminating information and reassuring people, as children can be used to educate their parents.

In contrast, there was some suspicion from the men about the current focus on public transport. Questions were raised about whether this was a way to force cars off the road. In a similar vein, there were also concerns about forcing people to buy more expensive hydrogen fuelled cars, rather than having their existing car converted and that only newer cars would be able to be converted. The involvement of commercial car manufacturers served to reassure these men that new products would be cost competitive. They were sure that car manufacturers would not invest in developing products using a technology that is too expensive for consumers to purchase. However, they were seen as having a stake in making existing cars obsolete. The men recognized that hydrogen fuel will not solve congestion problems and this left some room for suspicion that the government would still use the tax system to pressurize people off the road.

There was some a belief that:

"We will get forced in to it anyway and won't have much of a say in it." Man

In contrast with the women, some of the men had little understanding of the Government's role in ensuring appropriate regulations are in place and that the UK attracts inward investment from international companies seeking to locate production plants. They tended to see the technology as being market led, driven by the private sector. Indeed, support from national politicians reassured some of the men but not others because politicians were seen to *"jump on bandwagons"* or disagree with each other *"because that's what they're supposed to do"*. Some felt that the scientific community needed to speak out in favor of hydrogen but others were skeptical of their involvement.

"Why trust them so much? It was trumpeted that nuclear power was safe and battery powered cars would save the day but they ran into problems. They do that with all sorts of technologies." Man

Some men believed that persuading people to use hydrogen fuel will come down to *"the specifications"* for the cars and their value for money. However, the expert was warned that vested interests from somewhere would oppose a hydrogen economy:

"Someone will set up a group to say they don't like it." Man

Participants were not given information about other forms of alternative energy. Nevertheless, wind power and bio fuels were raised by the participants. The men felt that another technology might come along and replace hydrogen in the not too distant future.

7. Discussion

Although this study was not statistically validated or structured, it has provided insight into the public attitude to hydrogen in Wales, and provides exploratory findings that can be used as a base for future work. The idea that Wales could become self-sufficient and a leader in this field aroused national pride. It will be interesting to discover if the findings of this study are transferable to the rest of the Wales, including rural and more bilingual areas. In particular, the rural/urban divide needs to be explored given the recognition that pollution could merely be displaced from the point of use (towns and cities) to the point of production (more rural areas).

Gender differences were apparent. Some of the men who took part in this project were very negative. Nevertheless, both the men and women said that they thought that men would want to "*pull things apart and try to look for reasons* [to dismiss a technology]" and that "*women are more accepting* [of technology]". Women also thought "*men don't seem to accept change quite so easily.*" This directly contradicts the Schulte et al. (2004) and LBST (2003) studies that found that men were more accepting of hydrogen and hydrogen technology. It should also be borne in mind that the men in our group had more knowledge of hydrogen as a chemical and Shaw (2002) found that the better educated are more skeptical of scientific developments.

The two main concerns were found to be safety (both of use and in production) and cost. With respect to safety, the existence of tried and tested technologies was reassuring; the women more often identified parallel situations (such as the transition from town gas to natural gas in the UK) that had gone well and this reassured them about hydrogen. Indeed, the men who were less concerned than the rest of their group about safety also referred to previous and current situations (such as the introduction of LP gas vehicles) to reassure others in their group. However, unless the technology is cost effective, in fact more cost effective than current technologies, participants would be reluctant to shift to hydrogen technology. Cost remains paramount, even in light of environmental considerations. Hence, environmental arguments alone seem unlikely to change fuel usage behavior, based on these findings. Participants did find the environmental argument to be reassuring and something that makes hydrogen worthy of consideration but not compelling. Indeed, biological and renewable energy sources were seen as the most desirable ways forward for hydrogen production.

It was viewed by some, that:

"*Most things work on a proof of a track record. So once the tests have been done and they have proved themselves, I think most people are going to go for it, it's all down to the way it's marketed.*" Man

One of the women pointed out that the time for reflection between the two sessions, separately from the extra information presented in the second session, had enabled a different perspective. Any information strategy must therefore realize initial reactions may be hostile. As one participant said "*it's like with anything, people need time to get used to it.*"

Any project that sets out to engage the public with hydrogen fuel must provide information about the cost, safety and production of the fuel. In addition, all dialogue/communication activities to engage with the public must use illustrations, since visuals made a clear impact on views in the group sessions. Based on the initial focus group research, the biggest issues related to the future of hydrogen fuel are mainly related to production, safety at the point of use, cost and performance against the alternatives. However, some participants were sceptical of politicians, while others were sceptical of scientists; hence it is recommended that any event includes a spread of experts.

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Group 1 men

Age	Social Grade
34	E
25-55	D
25-55	B
25-55	C1
25-55	B
25-55	B
29	D
25	C1
42	D

Group 2 women

Age	Social Grade
38	C1
25-55	C1
25-55	C2
55	C2
25	C1
45	D
48	C1
25-55	B
25-55	C1

Appendix 2

The Potential for Hydrogen Enriched Biogas Production from Crops: Scenarios in the UK

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Abstract

There is increasing international interest in developing low carbon technologies to provide hydrogen renewably. Hydrogen can be produced through dark anaerobic fermentation using carbohydrate rich substrates, and methane can be produced in a methanogenic second stage. The suitability a range of crops for hydrogen and methane production in the UK is examined, using selection criteria including yield, harvest window and composition of the crops. The annual potential for hydrogen and methane production is calculated using the selected crops, taking into account the energy required to grow and harvest the biomass and run the process. The fermentable energy crops fodder beet, forage maize, sugar beet and rye grass were identified as the most suitable substrates for this farm-scale process. A conservative estimate of the amount of agricultural land in the UK excluding permanent grassland not already used for food production or energy crops (currently unused "set-aside" land) has been made (294,960 hectares). If this was used to grow a rotation of the selected crops, 9.6 TWh net energy could be produced per year. This equates to electrical power for 2.2 million homes in the UK annually and a reduction of CO_2 emissions by over 2.3 million tonnes per annum in the UK.

Keywords: sustainable hydrogen production, fermentation, biomass, energy crop

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Introduction

The UK, in common with many other countries, faces a number of challenges in its energy sectors. These include security of supply, achieving a reduction in CO_2 emissions and delivering improvements in local air quality. Currently the UK produces 395 TWh of electricity per annum [1] and imports 5TWh [2]. The UK also consumes 644.5 TWh in road, rail and air transportation [3]. It is likely that the UK will become a net importer of natural gas by 2006 and of oil by 2010 [4]. By 2020 it has been estimated that up to three quarters of the UK's primary energy consumption will be imported [5]. Dependence on imports has balance of payment and security of supply implications. At present some 98% of the UK total energy demand is met from fossil fuels. Through ratification of the Kyoto Protocol [6] the UK is committed to reducing CO_2 emissions by 12.5% below 1990 levels by 2010 [4].

The transport sector is one of the biggest contributors to CO_2 emissions in Europe and the European Commission has provided the target of 5% transport fuel to be hydrogen by 2020 [7]. Until fuel cells become commercially available, hydrogen can be used in internal combustion (IC) engines and turbines. Hydrogen mixed with methane in an IC engine is a commercial technology which can significantly reduce CO_2 and other emissions and improve fuel combustion efficiency. Vehicles can be converted to run on a hydrogen/methane mixture cost effectively, allowing for an incremental introduction of hydrogen to the fuelling infrastructure. This vehicle technology can be seen as an immediate bridge between the current hydrocarbon economy and the future hydrogen energy economy.

Use of hydrogen as a fuel is potentially a zero carbon technology, if hydrogen is produced using sustainable sources of energy. Currently, hydrogen is predominantly produced from fossil fuels; in the UK approximately 95% is generated by steam methane reforming [8]. Hydrogen can be produced sustainably by electrolysing water using electricity from renewable energy sources (e.g. wind, marine and solar), through the utilisation of energy crops and waste streams or other methods

[8]. Biomass has the potential to contribute to the mix, provided appropriate technologies can be developed for its conversion to hydrogen. Woody biomass with low water content is suitable for gasification/pyrolysis while wet biomass with high carbohydrate content can be converted to hydrogen and organic acids through the action of fermentative bacteria.

Fermentative hydrogen and methane production

Considerable research effort is evident from the literature on biologically produced hydrogen [9]. Reactor systems utilizing dark fermentative processes for hydrogen production are likely to resemble the highly developed methanogenic anaerobic digestion technologies used in waste and waste water treatment [10]. In studies on methane production by anaerobic digestion, an organic acid-producing first stage, similar to fermentative hydrogen production, has been found to give an increased rate of substrate decomposition, higher methane yields and improved process stability compared to the equivalent single stage system [11]. An integrated and sustainable system for production of hydrogen and methane from biomass in a two stage system is proposed (Figure 1). A selection of co-products, particularly from the food industry, could be used as feedstocks, as could crops specifically grown for the process. Dark fermentation to hydrogen is a technology that could be managed and operated on a farm scale, as is already the case with anaerobic digestion to methane. If crops already grown in the UK were suitable, farmers could use the existing sowing, growing and harvesting technologies together with their experience to minimise energy input. The biomass can be used at the site of production avoiding transportation, and can be harvested just before use, avoiding deterioration. For this paper we have chosen the scenario in which the crops receive no pre-treatment other than harvesting.

Unlike biomass for combustion/gasification/pyrolysis technologies, which may be woody, the crops needed in dark fermentation must be readily biodegradable. Carbohydrate-rich organic material, low in lignin, is the preferred substrate. Hydrogen production by fermentation can use a wide range of carbohydrates, while fermentation to ethanol using yeast can only utilise a few simple sugars [12]. Biomass such as root crops [13], fodder grass [14] or wheat industry co-products [15] have been shown to be viable substrates for dark fermentative hydrogen production. Fermentative bacteria producing hydrogen may be obtained in uncharacterised mixed cultures from natural sources such as anaerobically digested sewage sludge [9]. Carbohydrate rich crops can be directly fermented to produce hydrogen and CO_2 as shown in equations (1) and (2) for a six-carbon sugar (hexose). This will result in a mixture of acetic and butyric acid, with (usually) smaller amounts of other fermentation end products. The maximum theoretical stoichiometric yield of hydrogen is 4 moles hydrogen per mole hexose if the fermentation end products were only acetic acid, CO_2 and hydrogen (Equ.1). If butyric acid is the end product the maximum yield is 2 moles hydrogen per mole hexose (Equ. 2) [15, 16].

$$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2 \tag{1}$$

$$C_6H_{12}O_6 \rightarrow CH_3CH_2CH_2COOH + 2CO_2 + 2H_2 \tag{2}$$

The acetic and butyric acids, together with other fermentation end products and any undigested biomass, can then undergo methanogenic anaerobic digestion and the effluent can be used as a fertilizer, as there is little or no loss of N, P, K or other nutrients. Thus the energy inputs and the financial costs of growing the biomass substrate will also be reduced. This strategy allows traceability and could give outputs compliant with the specification for composted materials BSI PAS 100 [17] for utilisation of the process residue to land [18].

To date there is no study on the contribution that fermentative hydrogen enriched biogas production could make to the energy mix of countries. The authors are members of the UK`s Sustainable Hydrogen Energy Consortium (UK-SHEC) [19] and thus have selected the UK for initial evaluation. This paper identifies the land available for growing biomass crops, types of crops suitable for fermentative hydrogen and methane production, annual availability of these crops, their potential hydrogen and methane yield and the likely energy contribution of this process to the UK.

Land available for growing biomass crops in the UK

The UK has a geographical area of 24 Mha of which over 70% is currently needed for agriculture, according to the Department for Environment, Food and Rural Affairs [20]. Figure 2 shows land used by the UK agricultural industry in 2003 [20].

In England, the largest proportion of agricultural land (45%) is suitable for arable crops whereas Scotland, Wales and Northern Ireland have a lower percentage of arable land (Table 1). The category "arable" refers to production of crops for human and animal consumption but, increasingly, to crops for non-food uses including energy crops. In common with other countries in the European Union (EU), the UK has a significant proportion of land which has been removed from food production i.e. set aside. "Set aside" land is left fallow or used for growing non-food crops with industrial uses. The EU compensates farmers for their loss of income (as derived from food crops). The amount of land to be taken out of production, decided by the EU's Agriculture Council, varies from year to year depending on the level of production and stocks world-wide. For 2005 the percentage to be set aside is 8% of all agricultural land, excluding permanent pasture and rough grazing [21] (664,960 ha in the UK). Since the Mid Term review in 2003 [21], farmers can grow crops on set aside land which are not for human or animal consumption. The scenario considered in this paper is that set aside land not currently claimed by farmers (calculated from figures in Table 1) is converted to growing suitable energy crops. This would give 294,960 ha of land available for hydrogen production in the UK. This is a conservative estimate as it does not include currently used set aside land or permanent grassland, as pasture grasses could be used in the production of hydrogen. No existing arable land has been included since energy crop production may not be cost effective.

Crops considered for fermentative hydrogen and methane production

In contrast to biomass typically used in thermochemical processes, substrates for fermentation need to be low in lignin, high in carbohydrates and have a high moisture content. The ideal energy crop would be characterised by the highest possible yield (dry matter per hectare) with the maximum carbohydrate content, low energy input to produce the crop, low cost of production and low nutrient requirements [22]. These features can be dependent on climate, soil, water consumption, pest resistance and fertilizer requirements which are country specific.

Candidates for energy crops to be grown in the UK were subjected to a systematic selection process to identify the most suitable crops for anaerobic fermentation and their ability to fit within current agricultural practices and policy barriers. The crops that were considered initially were: barley, flax, fodder beet, forage maize, hemp, miscanthus, oats, perennial rye grass, potato, reed canary grass, sugar beet, sweet sorghum, switch grass and wheat (whole crop). The criteria for crop selection were productivity levels, carbohydrate content and harvest windows. All of the crops selected comply with set aside rules, and can be grown and harvested using standard agricultural machinery and practices. All crops chosen could be grown in UK climatic conditions, although trials on sweet sorghum have only begun recently.

Crop yields, harvest windows, composition and energy input.

In Table 2 the average yields of dry matter and fresh matter for each crop in identified temperate countries are given. In some cases (as indicated in Table 2) dry matter was derived using published water content data for the crops. For dry matter yield (in t ha-1) Table 2 shows fodder beet (13.6-17), forage maize (17-21), miscanthus (7-30), perennial rye grass (8.5-23), sugar beet (12.65-13.53), winter wheat (whole crop) (14) and sweet sorghum (20-27) have some of the highest yields.

The harvest windows of the crops are important in maximising the number of days per year that the fermentation process could operate. The harvest windows for the crops can be seen in Figure 3, indicating when crops can be used in the fermentation process directly after harvesting, or stored for later use. During April and May there are no reported harvest activities. Only miscanthus could be harvested during February and March. Some crops can only be harvested in one month (wheat and sweet sorghum), whereas other crops like beets, perennial rye grass or potatoes have a longer period for collection. Of the crops indicated in Table 2 it is possible to store sugar beet, forage beet or energy grasses. Crops cannot be stored by conversion to silage, as in this process carbohydrates are converted to fermentation end products.

Table 3 gives compositional crop data of % dry and/or fresh matter occurring as soluble sugars, starch, water-soluble carbohydrates, α-cellulose, hemicellulose, pectins and lignin. In some cases no compositional data was available for specific elements such as soluble sugars, starch or water soluble carbohydrates which can be used in the hydrogen production process. α-cellulose, hemicellulose and pectins are likely to be converted to hydrogen more slowly, but can be degraded to produce methane. However, lignin can affect the availability of these substrates, with a higher level of lignin reducing the hydrogen yield. Crops with the highest content of soluble sugars are sweet sorghum, perennial rye grass, oats, sugar and fodder beets. Some of the highest starch contents were found in potatoes, oats, barley and fodder maize. In most cases crops contain large amounts of cellulose and hemicelluloses ranging from 13%-74% dry matter. It can be expected that the crops with high lignin content such as reed canary grass, miscanthus and wheat (whole crop and straw) are likely to be problematic to ferment to hydrogen and methane production.

While differences in yield and composition exist between the crops, other factors such as energy input may negate any yield benefits. Energy inputs needed to grow and harvest the crops are shown in Table 4 on a per hectare basis. This data includes agrochemicals (including pesticides and fertilisers) and machinery activities (ploughing, harvesting etc.) but not transport or storage. In Table 4, data for miscanthus, reed canary grass and switch grass have been averaged over their expected lifetime (20 years) [23] as energy inputs in the early stages of growing these crops are very high, but once established reduce dramatically. Data in references [70], [71] and [74] include an 8% addition for energy to transport the material off site. As this study considers farm based systems there is no such requirement. So in Table 4 energy inputs given in these references have been reduced by 8%. Energy inputs range between 4,082 MJ ha-1 for reed canary grass to 23,920 MJ ha-1 for wheat or forage maize.

Potential hydrogen and methane yield

Assumptions on the operation of the reactors and yields of hydrogen and methane

The calculations used to estimate hydrogen and methane yield were based on work by Hussy *et al.* which found that >95% of fine particulate wheat starch [15] and 90% sucrose from sugar beet [13] convert to hydrogen and fermentation end products. There is evidence in published work that clostridia are capable of converting cellulose into hydrogen [24] [25] [26] however this has not been factored into the calculations. The yield of hydrogen varies between 1.7 and 1.9 moles of hydrogen per mole of hexose in sugar beet and starch respectively [13] [15] at a substrate concentration of $10kgm^{-3}$. A yield of 0.7 moles hydrogen per mole hexose (assuming all total sugar is hexose) is reported for an extract of perennial rye grass [14]. Table 5 indicates which of the three hydrogen yields was applied to each crop, crop yield and carbohydrate content values used. Other assumptions were:

- Hydraulic retention time (residence time) of the hydrogen reactor is dependant on substrate; a hydraulic retention time of 12 hours [14], 15 hours [12] and 20 hours are suitable for the hydrogen production operating on starch, sugar beet and grass based substrates respectively.
- Substrates in the influent at 50kg (dry matter) m^{-3} [27]
- A hydraulic retention time of 15 days for the methanogenic anaerobic digester.
- 90% of the acetic and butyric acid resulting from the hydrogen fermentation is converted into methane.
- The methane yield from the holo-cellulose (see Table 5) entering the anaerobic digester after the hydrogen fermentation stage is on average $0.3m^3$ methane per kg volatile solids added [28].

- Assume 1 mole hexose degraded in H_2 stage gives 0.5 mole acetate (hence 0.5 mole methane in anaerobic digester stage), and 0.75 mole butyric acid [29] (hence 1.9 mole methane in anaerobic digester stage)

The size of a medium to large farm scale plant was calculated for a 250 ha farm operating using substrate grown on 20 ha cropped for 10 months of the year. Using ryegrass, maize and sugar beet, the maximum crop per month is 26 tonnes dry matter, delivered at 50kg dry matter per m^3 hydrogen reactor in 15 hours. The reactor sizes were $7.5m^3$ for the hydrogen reactor and $110m^3$ for the methane reactor.

The data for each crop from Tables 1, 2 and 3 was used to develop a set of assumptions to calculate energy output. Table 5 indicates the data used for the calculation of hydrogen and methane production and was created from the mean crop yield values, average compositional data and likely hydrogen yield. Table 5 was then used to calculate the energy output per hectare of each of the crops using equation 3.

Calculations of the net energy production

Equation 3 was developed in order to estimate the overall net energy production for a crop grown on one hectare of land. The equation calculates the energy produced and the energy consumed in the process to give net energy production of the system.

$$E_N = Y_c\left[WSC\,S\left[(Y_{H2})(H_{2\,LHV}) + \left[(Y_{ac}) + (Y_{bu})\right]CH_{4\,LHV}\right] + \left[\%CHC \cdot CH_{4\,LHV}\right]\right] - E_1 - E_2 \quad (3)$$

where,

Y_C=Crop yield (t ha-1 dry matter)

WSC S= Water soluble carbohydrates and starch (% dry matter)

Y_{H2}=Reported H_2 yield for specified crop (mole hydrogen per mole converted)

$H_{2\,LHV}$= Hydrogen low heating value (120 MJ kg-1) [8]

CHC= α-Cellulose and hemicellulose (% dry matter)

Y_{ac}= Reported methane yield from acetic acid yield (mole methane per mole acetic acid converted) [14]

Y_{bu}= Reported methane yield from butyric acid yield (mole methane per mole butyric converted) [14]

$CH_{4\,LHV}$= Methane low heating value (50 MJ kg-1)

E_N= Net energy (MJ ha-1)

E_I= Energy Input to grow the crop (MJ ha-1)

E_2= Energy to run the process (36 MJ yr-1) quoted in [30]

This equation was applied to the crop data in Table 5.

Results and Discussion

Table 6 shows the five highest net energy yielding crops are sweet sorghum (223,928 MJyr ha-1), forage maize (121,522 MJyr ha-1) fodder beet (117,063 MJyr ha-1), perennial rye grass (114,189 MJyr ha-1) and sugar beet (112,624 MJyr ha-1). Sweet sorghum has a one month harvest window (Figure 3) and is not a proven crop in the UK so farmers would be reluctant to commit to commercial growth of a crop currently involved in trials. Fodder beet and sugar beet are almost identical crops, and both are harvested over 5 months and may be stored for several months. However, of the two sugar beet was preferable as it has the higher net energy. Therefore the most appropriate crops identified were forage maize, perennial rye grass, sugar beet and fodder beet.

The overall UK energy contribution was estimated by assuming the allocation of the available landmass of 294,960 ha divided equally between forage maize, sugar beet and perennial rye grass, in order to facilitate crop rotation. Thus by utilising the available 'set aside' hectares of eligible (but not currently used) land, from the figures in Table 6, an estimated 9.6 TWh of energy could be produced. The average energy ratio is 10.4% as H2 and 89.6% as CH4, however sugar beet produces a higher ratio of H_2 (see Table 6). Research efforts could be directed at improving this ratio. This equates to electrical power for 2.2 million homes in the UK annually (assuming an average household consumes 4,290KWh yr-1 of electricity [31]). The overall CO_2 emissions reduction is estimated to be over 2.3 million tonnes per annum in the UK. The estimated reduction of CO_2 was calculated using the conversion efficiency of 0.24 $KgCO_2$ KWh-1. [77]

The estimated yields used in this paper were of moderate yields (not the higher end of production) in Northern European growing conditions similar to that of the UK. Set-aside is high quality land that would normally be under food cropping and thus it would be expected that these are achievable yields. The two determining factors for the use of set aside land proposed here would be the outcome of a full economic comparison with other energy and non food crops and any strong political agricultural policy in regard to the use of set-aside land.

Only crops from unclaimed set aside have been considered here. The energy contribution of this technology could be considerably increased if food industry co-products, municipal solid waste, crops residues and crops growing on other agricultural land were used.

Conclusions

- Sugar beet, forage maize, fodder beet and perennial rye grass are the most appropriate energy crops to grow for fermentative hydrogen and methane production in the UK as the net energy output could be 112,624 MJyr ha-1, 121,522 MJyr ha-1, 117,063 MJyr ha-1 and 114,189 MJyr ha-1 respectively and these crops provide feed for the process over ten months.
- Sweet sorghum has a potentially high energy output of 223,928 MJyr ha-1 if used in this process, but the crop harvest window is only one month and the crop is unproven in the UK.
- The use of 294,960 ha of currently unused set aside land would in the UK provide 9.6 TWh of net energy, 10.4% as H_2 and 89.6% as CH_4 in accordance with the assumptions set out

in this paper. This would correspond to savings in emissions in the order of 2.3 million tonnes of CO_2 per annum.

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Table 1 Agricultural land use ('000 Hectares)

	Scotland	England	Wales	N Ireland
Reference	[32]	[33]	[34]	[35]
Total Agricultural land	5197	9583	1639	1074
Arable land (tillage and grass under 5 years old)	965	4499	183	191
Permanent grassland (over 5 years old)	903	2816	962	710
Rough grazing	3329	612	406	153
All other agricultural land	-	1369	5	17
Set aside claimed	76	287	4	3

Table 2. Average yields of crops in temperate climates

Crop	Yields t ha-1 (fresh)	Yields t ha-1 (dry matter)	Reference:	Country
Barley	5-6	4.25-5.1	[36]	UK
	5-7	2.75 straw	[21]	UK
	4.53		[37]	UK
Flax	4-8	3.7-11.6[a]	[36]	UK
Fodder beet	80		[21]	UK
	80-100	13.6-17	[36]	UK
Forage maize		17-21	[38]	Ireland
	40		[21]	UK
Hemp	5.5	4.54[b]	[21]	UK
	8-12	6.6-9.9[b]	[36]	UK
Miscanthus	15		[36]	UK
		11-18	[39]	UK
		7-24	[40]	UK
		12-14	[21]	UK
		12-30	[22]	UK
		11	[41]	UK
Oats	5.5	4.7	[36]	UK
	5.25-7.75	3.5 straw	[21]	UK
Perennial ryegrass	10-20		[36]	UK
		8.5-19.2	[42]	France
		15	[43]	The Netherlands
		12	[44]	UK
		18-23	[45]	UK
Potatoes	40		[36]	UK
	36-44-52	2.3-3.4[c]	[21]	UK
	32		[37]	UK
Reed canary grass	12-18		[36]	UK
		7-8	[41]	UK
Sugar beet	55	12.65-13.53	[36]	UK
	40		[37]	UK
	34-60		[46]	UK
	45-80		[47]	UK
	42.5-55-67.5		[21]	UK
Sweet sorghum		20-27	[48]	(Northern) Italy
		25	[36]	UK
Switch grass	12-18		[36]	UK
		8-13	[41]	UK
		9	[49]	Iowa (USA)
		8	[22]	UK
Winter wheat	7-9		[36]	UK
	5-7		[37]	UK
	6.7-8.25-9.75	3.5 straw	[21]	UK
		14 (whole crop)	[22]	UK

[a] Using [50] 91.6 % of fresh is dry matter

[b] Using [51] 82.57 % (mean value) of fresh is dry matter

[c] Using [52] 2.2-7.7% of fresh is dry matter

Table 3. Composition of prospective crops (Expressed as % dry matter (dm) or fresh)

Crop	Soluble sugars	Starch	WSC[a]	Pectin	α-cellulose	Holo-cellulose	Hemi cellulose	Lignin	Reference
Barley		55.1dm				13.7dm			[53]
Flax				3dm	65dm		16dm	2.5dm	[54]
					72dm		18dm	3dm	[50]
Fodder beet	12.2fresh		63.9dm						[55]
Forage Maize whole plant			22.1dm		30.3dm		19.5dm	4.8dm	[50]
			25.4dm		36.8dm		27.4dm	5-8dm	[50]
		31dm				36dm			[56]
Hemp	5-6dm				69-74dm			1.5dm	[57]
					67dm		16dm	3.3dm	[54]
				3dm	73dm		7.6dm	3dm	[50]
Maize					33.2dm		24.6dm	15.1dm	[50]
Miscanthus					57.9dm		16.1dm	8dm	[50]
					44dm		24dm	17dm	[58]
Oats (grain)		54-64dm							[59]
			48dm			6.1dm			[53]
					34.9dm			4.3dm	[60]
Perennial ryegrass	25.3dm	3dm			(57.5dm)b				[61]
Potatoes		85-87dm							[52]
Reed canary grass					28dm		22dm	14dm	[62]
					28-34dm		20-23dm (including pectin)	7-18dm	[63]
Sugar beet	15.5-18 fresh								[64]
					26dm		28dm	4.5dm	[50]
	17.10 fresh			21.75dm	29dm		21.75dm		[65]
	14-15 fresh								[66]
	17 fresh								[67]
	17 fresh				4.9-6.3dm				[36]
	64.7-70dm								
Sweet sorghum	15.8 fresh				5.5fresh		4.5fresh	3.3fresh	[68]
	43.58dm				25.1dm		22.34dm	3.8dm	[48]
Switch grass					30-50dm		10-40dm	5-20dm	[22]
					31.6dm		36dm	6.1dm	[49]
	5.5dm	5.65dm							[69]
Wheat straw					33.2dm		24.6dm	15.1dm	[50]
Wheat whole plant		10.5dm			33.7dm		13.4dm	7.5dm	[50]
					33-40dm		10-40dm	15-20dm	[22]

[a]WSC, Water soluble carbohydrates
[b]Combined value for α- cellulose, Hemi-cellulose and lignin = 57.5dm

Table 4. Energy inputs per hectare per year from annual cropping

	Energy inputs (MJ ha-1)	Reference
Barley	16,563	[70]
Flax	8,656	[71]
Fodder beet	18,247	[70]
Forage maize	17,630	[72]
	23,920	[73]
Perennial rye grass	4,710	[74]
Hemp	12,234	[71]
Maize	17,630	[72]
Miscanthus	6,234	[23]
Oats	15,094	[70]
Potatoes	48,200	[70]
Reed canary grass	4,082	[23]
Sugar beet	18,247	[71]
	21,400	[75]
	20,240[a]	[73]
Sweet sorghum	18,400[a]	[73]
Switch grass	6,330	[23]
Wheat	21,895	[70]
	23,920[a]	[73]

[a]Modified from [72]

Table 5 Data used for calculating hydrogen and methane production

	Crop yield tdm ha-1	Carbohydrate for H_2 production as % of dm	Holo-cellulose for CH_4 production as % of dm	H_2 yield mol mol-1 hexose converted
Barley	4.5	55.1 starch	13	1.9
Flax	5.5	Not found	81	-
Fodder beet	14	63.9 WSC	21.75[a]	1.7
Forage maize	19	31 starch	36	1.9
Hemp	7	5.5 soluble sugars	82.3	1.7
Miscanthus	13.5	Not found	71	0.7
Oats	4.7	53.5 starch	6.1	1.9
Perennial rye grass	14	25.3 soluble sugars	57.5	0.7
Potato	3.4	86 starch	Not found	1.9
Reed canary grass	7.5	Not found	50	-
Sugar beet	13	67.35 soluble sugars	21.75	1.7
Sweet sorghum	24.5	43 soluble sugars	47.44	1.7
Switch grass	9.2	11.2 (starch and soluble sugars)	67.6	1.9
Wheat (whole plant)	14	10.5 starch	47	1.9

[a] Assume as per sugar beet for lack of data

Table 6. Calculated gross and net energy output per year

	Energy output from H_2 MJ ha-1	Energy output from CH_4 MJ ha-1	Total gross energy output MJ ha-1	Net energy output MJ ha-1
Barley	5,653	29,522	35,175	15,613
Flax	0	45,441	45,441	36,785
Fodder beet	19,263	116,046	135,309	117,063
Forage maize	13,429	125,723	139,152	121,522
Hemp	829	62,419	63,248	45,618
Miscanthus	0	97,767	97,767	91,533
Oats	5,733	26,812	32,545	17,451
Perennial rye grass	3,140	115,759	118,899	114,189
Potato	7,259	27,737	35,037	-13,163
Reed canary grass	0	38,250	38,250	34,168
Sugar beet	18,853	112,017	130,871	112,624
Sweet sorghum	22,685	219,642	242,327	223,928
Switch grass	2,338	73,180	75,519	69,190
Wheat (whole crop)	3,351	81,081	84,432	62,538

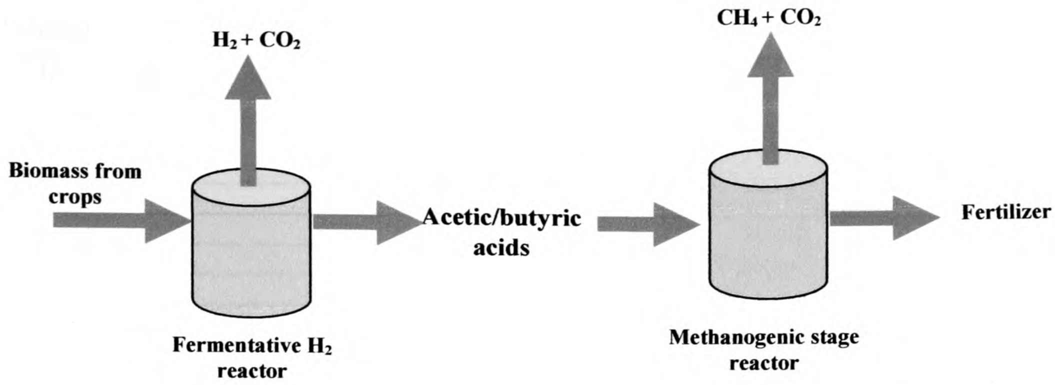

Figure 1. Two stage system for hydrogen and methane production from wet biomass.

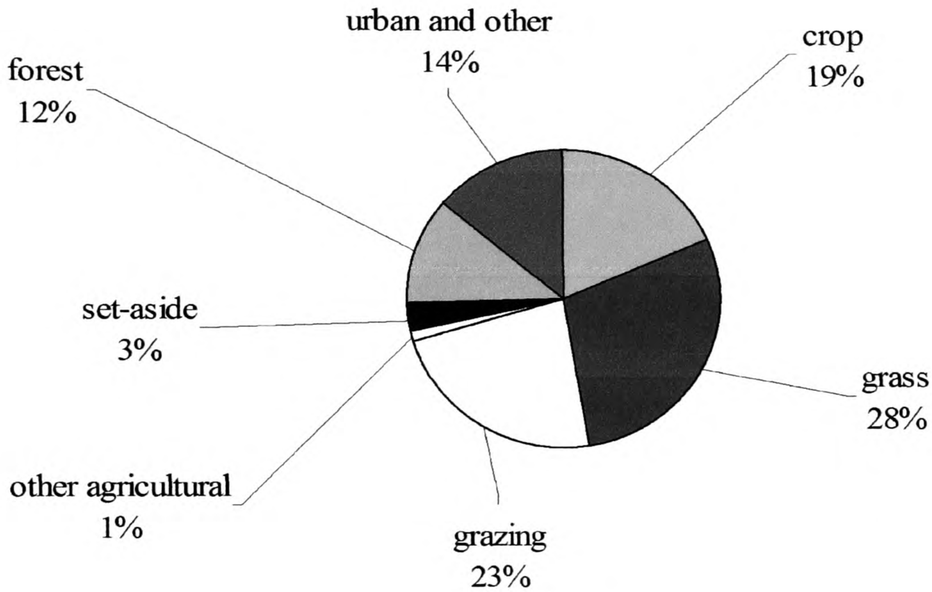

Figure 2. UK land use by agricultural and other uses in 2004 [20]

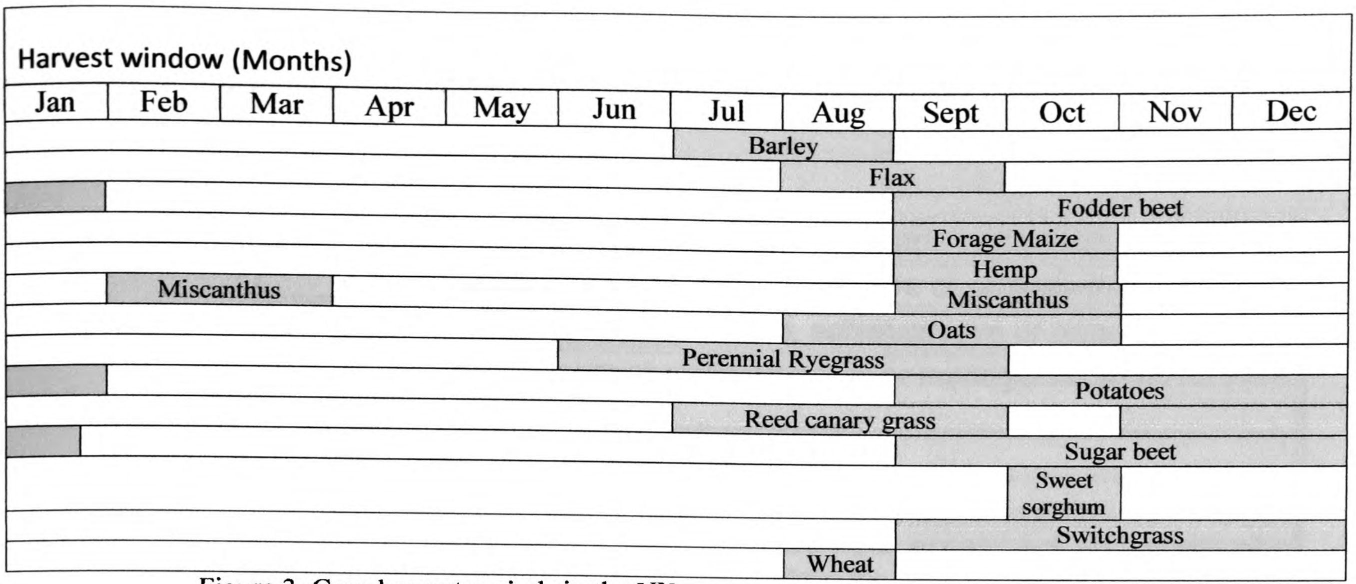

Figure 3. Crop harvest periods in the UK

Appendix 3

Social Grade Definition

Grade	Chief income earner's occupation
A	Higher managerial, administrative or professional
B	Intermediate managerial, administrative or professional
C1	Supervisory or clerical and junior managerial, administrative or professional
C2	Skilled manual workers
D	Semi and unskilled manual workers
E	Casual or lowest grade workers, pensioners and others who depend on the welfare state for their income

Appendix 4 - Derivation of net energy equation

The overall viability of an energy technology is whether the energy output is positive; this has lead to the calculation to determine the net energy of bio-hydrogen production as seen below (this is calculated per hectare):

We start with the understanding that:

Net Energy (E_N) = Output energy – Input energy

Where,

Input energy = Energy to grow crops (E_1) + Energy to run process (E_2)

$\therefore$ Energy (E_N) = output energy – (E_1 +E_2)

And,

Output energy = Energy from Sugars (to H_2) + Energy from acids (to CH_4) +Energy from hemicellulose and α-cellulose (to CH_4)

Or,

Output energy = $E_{(s)}$ + $E_{(Acid)}$ + $E_{(CHC)}$

So,

Net Energy (E_N) = $E_{(s)}$ +$E_{(Acid)}$ +$E_{(CHC)}$ – (E1 + E2)

To derive the energy from sugars ($E_{(s)}$)

First, we must calculate the value of sugar available from 1 kg of substrate (E_{S1kg}), this is calculated by using the known sugar content of 1 kg of substrate:

WSC s = 1kg substrate x % dry weight (WSC s) converted to moles.

The conversion from weight to moles is required to enable the amount of output products to be calculated, based on stoichiometry and known conversion rates to hydrogen as seen in table 2.3.

Then,

Hydrogen yield rate from sugar

Y_{H2} = molar hydrogen yield rate conversion. A conversion to weight is undertaken after calculation.

Finally,

To convert to energy, the lower heating value of hydrogen is used (H_{lhv})

$E_{(S1Kg)} = WSC\ s\ \ x\ Y_{H2}\ \ x\ H_{LHV}$

So, for total energy per hectare:

$E_S = Yc\ x\ WSC\ s\ \ x\ Y_{H2}\ \ x\ H_{LHV}$

To derive the energy from Acids ($E_{(Acid)}$)

We must calculate the derived acids from sugar, from previous equation $E_{(S1kg)}$. We take the molar value WSC s and derive the value of Acetic and Butyric acid content using values from table 2.3.

Yield from Acetic acid (Y_{ac}) = conversion rate to acetic acid from WSC s x conversion rate to methane from acetic acid

Yield from Butyric acid (Y_{bu}) = conversion rate to butyric acid from WSC s x conversion rate to methane from butyric acid

We get a total methane yield by adding both Acetic and Butyric acid yields. This can then be converted to methane using lower heating value of methane.

The final energy equation for $E_{(acid)}$

$E_{acid1Kg} = (WSCs\ x\ Y_{ac}\ x\ CH_{4LHV}) + (WSCs\ x\ Y_{bu}\ x\ CH_{4LHV})$

Simplified:

$E_{acid1Kg} = WSCs\ \ x\ CH_{4LHV}\ (\ Y_{ac} + Y_{bu}\ )$

For total energy per hectare from acids:

$E_{acid} = Y_c\ (WSCs\ \ x\ CH_{4LHV}\ (\ Y_{ac} + Y_{bu}\ ))$

Energy from hemicellulose and α-cellulose(E_{CHC})

To derive the energy from second stage reaction we must first calculate the energy output form 1 kg of substrate. This is done by calculating the hemicellulose and α-cellulose content (CHC). Using this value we are able to calculate the conversion of CHC to methane using the information in table 2.3 which is expressed as (%) and converted to energy by using the lower heating value of methane ($CH_{4\ LHV}$).

$E_{chc} = 1\ x\ \ \%CHC\ x\ CH_{4\ LHV}$

In order to calculate the energy output per hectare of the Hemicellulose and α-cellulose we then need to multiply the above equation with the kg crop yield per hectare.

$E_{chc} = 1 \times \%CHC \times CH_{4\,LHV} \times Y_c$

Output energy = $E_{(s)} + E_{(Acid)} + E_{(CHC)}$

Output energy = $(Yc \times WSC\ s \times Y_{H2} \times H_{LHV}) + (Y_c\,(WSCs \times CH_{4LHV}\,(Y_{ac} + Y_{bu}))) + (1 \times \%CHC \times CH_{4\,LHV} \times Y_c)$

Simplified to:

Output energy = $Y_c\,(WSC\ s\,(Y_{H2}\,H_{2LHV} + ((Y_{ac} + Y_{bu})CH_{4\,LHV})) + \%CHC \times CH_{4LHV})$

Substituting the above derivation of terms into the original equation of:

Net Energy (E_N) = Output energy – Input energy

We derive a final Overall energy calculation of:

$$E_N = Y_c\left[WSC\ s\left[(Y_{H2})(H_{2\,LHV}) + \left[(Y_{ac}) + (Y_{bu})\right]CH_{4\,LHV}\right] + \left[\%CHC \times CH_{4\,LHV}\right]\right] - E_1 - E_2$$

Appendix 5 – Report submitted by PSP

People Science & Policy

Public Perceptions of Hydrogen as an Energy Source in Wales

Report prepared for

Hydrogen Research Unit
The School of Technology
University of Glamorgan

04/022/sk
October 2004

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Contents

Executive Summary

Introduction

Hydrogen has great potential as a fuel of the future. Hydrogen powered bus services are operating in London and many countries are exploring the use of hydrogen as part of their future energy strategy. If hydrogen becomes a major energy source, Wales could create employment opportunities in the development and production of the fuel.

Aims and objectives

The aim of this project was to inform the development of an outline strategy to engage adults in Wales in discussions about hydrogen fuel. The objectives set out for the project by the University of Glamorgan (UoG) team can be summarised as to:

- understand public perceptions of hydrogen fuel;
- determine the broad acceptability of hydrogen fuel technologies;
- identify educational needs and the appropriate level of communication; and
- develop an outline framework for the delivery of a public engagement strategy.

Methodology

Two reconvened focus groups were run just outside Cardiff in September 2004. Both sessions of both groups lasted two hours. One group comprised nine women, the other seven men; all were aged 25-55. A member of the UoG technical research team took part in the second sessions to provide answers to the questions identified in the first sessions. The recruitment questionnaire can be found at Annex 1. Topic guides for both sessions and the self-completion questionnaire that provided background data on attitudes to science and the environment can be found in Annexes 3, 4 and 5.

Knowledge and first impressions

The participants

As a group, participants were generally supportive of science but on the whole they were more interested in the cost of hydrogen than in the environmental benefits.

Hydrogen

The word 'hydrogen' conjured up images of explosions and bombs for some but not all the participants.

The men appeared to know more technically about hydrogen that the women. They mentioned that it was flammable, light and abundant ant they knew it was a 'clean' fuel, although there was some confusion with helium.

With regard to hydrogen powered vehicles, participants could not see why they should look different from conventional vehicles and believed that the manufacturers would not want them to look different.

Once it became clear that water was an emission there were concerns about the impact of this on the local climate and whether it would be damper.

Safety

There were two main views on safety. One group believed that anything would have to be very safe before it was put on the market and some thought pressure groups played a role here. The other group thought that there would still be issues of flammability and explosions to deal with, particularly if there were crashes. Those who were less worried about safety cited the dangers inherent in using petrol. Lesser concerns were the heat of the steam emitted and the smell.

The potential to employ existing technology was reassuring to participants.

Cost

Cost, rather than environmental benefit, was the primary consideration for participants in considering whether they would willingly choose hydrogen as a fuel source. This related to the purchase of the fuel and of machinery, such as cars, that run on hydrogen fuel.

Environment

We have already mentioned concerns about the impact of steam on local weather conditions. Another environmental benefit was the lack of noxious fumes.

There was some awareness of global climate change and the potential role of hydrogen fuel in reducing carbon emissions. It was recognised, however, that using hydrogen fuel means that environmental problems will be largely shifted from the point of use to the point of production, unless new methods of production can be developed.

Production

Production methods
Participants' most favoured method of production was that involving algae and bacteria, as these were seen to produce the lowest levels of pollution. Production methods that were carbon neutral were more attractive than those that relied on conventional electricity.

Sequestering carbon dioxide was thought to be worthy of consideration as scientists might find a solution for this problem in the future.

Production plants
To some extent participants said that they would have the same concerns about the citing of a hydrogen production plant as with any other production plant, so the scale and impact of local pollution were highlighted.

By-products
Water as a by-product was seen as a potential problem. Not only because the atmosphere might be damper but also because water is a greenhouse gas.

Again, learning that hydrogen is currently produced industrially was reassuring to participants.

Storage

That hydrogen can act as an energy store was seen as in its favour.

Transportation

Some participants were concerned about the dangers during transportation but others felt that gases are currently transported safely and they assumed the fire brigade would be trained to deal with accidents.

Supply

Participants were unclear which types of organisations would supply hydrogen but were reassured by the information that oil companies are involved. This tended to reassure people that this was a long term venture.

Consumer availability was an important aspect of transferring to hydrogen fuels.

Usage

Participants were surprised to learn that there are buses running on hydrogen and that the car industry has long term research projects developing cars to run on hydrogen. Performance is important to both men and women in the choice of car but cost and reliability were at the top of the list of things participants considered when buying a new car.

The women's group assumed that the transfer to a hydrogen economy would be gradual and that people would have time to see hydrogen working before using it themselves. They saw publicly funded demonstration projects and financial incentives as an important part of the change over.

Some of the men were suspicious of government involvement and they had more trust in the scientific community's views.

Wales

Despite some misgivings about the technology, there was a consensus that for Wales to be a centre of excellence in the research and production of hydrogen fuel would be good for the country economically and intellectually.

Public communication strategy

Threats to hydrogen as a fuel source

From this project we have identified the following possible threats to the success of hydrogen as an alternative fuel: cost, safety and the impact of production methods.

The GM crops parallel

The main reasons for public rejection of GM crops have been identified as:

- health concerns about the impact of eating GM food;
- environmental concerns about the spread of GM pollen and cross-contamination;
- lack of choice (products were not labelled);
- lack of perceived benefits to consumers;
- control of the food chain by (US) big business, especially in the developing world;
- corporate profits; and
- the BSE experience and the lack of Government openness.

In this small project on attitudes to hydrogen fuel we found parallels with these concerns. Some of are more easily addressed than others. We see the main issues as relating to production with respect to:

- the methods of production;
- the safety of production plants;
- emissions from production plants and their visual impact on the landscape;
- the role of Government/politics;
- the role of big business; and
- the benefits of hydrogen as against other potential energy sources.

Ideas for dialogue projects

- Exhibitions with public meetings
- Dialogue with business and the public events
- Demonstrations and open days
- Alternative energy event
- Further research

As a group, participants were sceptical of both politicians and scientists, hence we recommend that any event includes a spread of experts.

Raising funds for dialogue

To engage with people on a more individual level UoG might consider an application to Sciencewise, the new grants scheme funded by the Office of Science and Technology (OST). This scheme requires matched funding, which must not come from public sector sources. The closing date for the first round of Sciencewise applications is 15 November 2004.

Other sources of funding might be the European Union, the Welsh Assembly, the Engineering and Physical Sciences Research Council and the previously mentioned industries.

1. Introduction

In the face of climate change and uncertain oil supplies – both in terms of the size of reserves and political stability in some producer countries – hydrogen has great potential as a fuel of the future. Already hydrogen powered bus services are operating in London and many countries are exploring the use of hydrogen as part of their future energy strategy. Hydrogen fuel offers a number of benefits at the point of use in that steam, rather than more polluting emissions, is released. If hydrogen becomes a major energy source, Wales (a European Union Objective 1 region) could create employment opportunities in the development and production of the fuel.

There are a number of ways of producing hydrogen fuel with greater or lesser environmental impacts and economic and social costs. The Hydrogen Research Unit within the School of Technology at the University of Glamorgan (UoG) is researching the potential of sustainable production of hydrogen fuel. This work is supported by the Engineering and Physical Sciences Research Council (EPSRC) and the Carbon Trust in particular.

In addition, the Unit has a two-year project part-funded by the European Union (EU) Regional Development Fund (Objective 1) to study the social and economic implications, as well as the technical implications, of moving to a hydrogen economy in Wales. Part of this project requires an understanding of public perceptions and current levels of awareness and acceptability of hydrogen fuel in Wales. People Science and Policy Ltd (PSP) was commissioned to undertake a small exploratory study into public perceptions and concerns.

1.1 Aims and objectives

The aim of this public perception project was to inform the development of an outline strategy to engage adults in Wales on hydrogen fuel. The objectives set out for the project by the UoG team can be summarised as to:

- understand public perceptions of hydrogen fuel;
- determine the broad acceptability of hydrogen fuel technologies;
- identify educational needs and the appropriate level of communication; and
- develop an outline framework for the delivery of a public educational[1] strategy.

1.2 Methodology

Two reconvened focus groups were run just outside Cardiff in September 2004. One group comprised nine women, the other seven men; all were aged 25-55. Both sessions of both groups lasted two hours. The recruitment questionnaire can be found at Annex 1.

The first sessions were run with a facilitator providing some basic information and gathering questions to be answered at the second session. The topic guide for this session was developed with input from a number of published research papers that reported on the findings of studies of public attitudes and concerns around the world. The list of publications referred to can be found in Annex 2.

[1] We interpreted this to mean public engagement in our ideas for projects.

Before the second session began, participants were asked to complete a short questionnaire to provide more information on their attitudes to science and the environment.

A member of the UoG technical research team took part in the second sessions to provide answers to the questions identified at the first session and to enable more in-depth discussion of the issues.

Topic guides for both sessions and the self-completion questionnaire can be found in Annexes 3, 4 and 5.

1.3 The report

This report has two main sections. The next section sets out the knowledge, attitudes and concerns identified from the research, highlighting the main issues any information strategy would need to cover. Section 3 then sets out some ideas for raising awareness of hydrogen fuels.

2. Knowledge and First Impressions

2.1 *Introduction*

This section begins with a short description of the views of the participants about science based on the self-completion questionnaire completed at the beginning of the second session. The core of this section then sets out participants' responses, knowledge, misconceptions and concerns about using hydrogen as a source of energy. The first sessions began with a brain storming on the word 'hydrogen' to identify how the general public might react to the idea of using hydrogen as a fuel. It went on to provide more information, to explore first thoughts and draw out questions. The second session provided answers to these questions and investigated in more depth participants' concerns about hydrogen fuel. In the conclusions to this section we highlight the main issues a public engagement strategy would need to cover.

2.2 *The participants*

As a group, the participants were generally supportive of science. None agreed with the statement "I am not interested in science and I don't see why I should be" and only one woman disagreed that 'science and technology are making our lives healthier, easier and more comfortable". There was also considerable trust in the regulation of science, with only one woman agreeing that "the speed of development in science and technology cannot be properly controlled by the Government". One of the men did not complete the self-completion questionnaire.

Previous work has found that an individual's attitude towards the environment is an important factor in attitudes towards hydrogen as a fuel source. We found that the participants were, on the whole, more concerned about cost than the environment in their choice of products, although some valued the environment more highly than others.

> *"This is where we all live, so it's got to be the first consideration".*
> Man

2.3 *'Hydrogen' – the image*

2.3.1 The word

In general the women were less concerned than the men at the mention of the word 'hydrogen', although for at least some individuals in both groups the word 'hydrogen' conjured up images of explosions. For the women this was just a general response to gases in general, for the men it related to the hydrogen bomb and the Hindenburg accident.

> *"It's just synonymous with the bomb as far as I'm concerned."*
> Man

One of the women was a hairdresser and she associated hydrogen with hydrogen peroxide.

2.3.2 The chemical

Everyone was aware that water is made up of hydrogen and oxygen (H_2O). The men, however, appeared to know more about hydrogen as a chemical, or at least they were more prepared to proffer information than the women. The men knew that hydrogen is:

- *"Flammable"*
- *"The first thing on the period table"*
- *"The simplest element"*
- *"Half of a bad smell"* [hydrogen sulphide – bad eggs]
- *"Very light"*
- *"Abundant"*

One man had heard of fuel cells in relation to hydrogen and one of the women had seen something in a newspaper about hydrogen being used as a fuel for transport.

Using a mock headline in a local paper announcing hydrogen fuelled buses in Cardiff elicited knowledge from some about noise levels. Some were aware that cars and buses run on hydrogen (fuel cells) would be quieter than standard vehicles. In general participants did not expect hydrogen powered buses to look any different from 'normal' buses. While they did not see why it would need to look any different, they also felt that the manufacturers would not want them to look any different. Moreover, several participants in both groups knew people who had converted their cars to run on LP gas, and these did not look any different.

There was also some awareness that hydrogen powered buses would be cleaner in environmental terms because hydrogen is a clean fuel and that the only emission would be water/steam. In the initial brainstorming one man said:

> *"It is a clean fuel."*
> *"The only emission is water and there is an abundant supply of hydrogen."*
> Men

However, there were instances where a little knowledge led to more confusion than clarity. For example, one man knew that water is H_2O, which led him to ask:

> *"If there is more hydrogen in the air won't that combine with the oxygen and produce water?"*
> Man

This, plus the fact that water is the main emission, stimulated a discussion about the impact of water being emitted on the local climate and whether it would rain more or the atmosphere be more damp.

Importantly, there was some confusion with helium, which probably stems from the similarity of the (unfamiliar) words and the use of both gases in airships.

> *"It makes you sound like Daffy Duck."*
> Man

2.4 Safety

There were two main views on safety. Firstly, there were those who believed that before anything was put on the market it would be heavily tested and therefore safe.

"Working in the bus industry before, I know the testing the buses go through is rigorous, compared to a car its another 50% again, if they have managed to get it into a bus it is going to be safe, 'cos they do put them though rigorous testing."
Man

"As long as we were told it was safe and we knew how to manage it, and knew the do's and don'ts. I am sure those of us who do have our heads screwed on, they are going to be responsible."
Woman

Secondly, there were those who were concerned about flammability and explosions, no matter what, and the latter was cited in association with the hydrogen bomb.

"I don't think you can get away from the bomb because when you talk about hydrogen people will think of the hydrogen bomb."
Man

Perhaps as a result of the awareness that hydrogen is *"highly"* flammable, there was concern in the men's group about safety to a far greater extent than in the women's group. In the second session, the expert showed them a photograph of two cars, one run on petrol, the other on hydrogen. Both had had a hole pierced in their tanks and a fire set. The hydrogen car is much less affected and it is clear from the photograph that the passengers would be safer. [See Annex 6.] Moreover, the explanation from the expert made it clear that passengers could survive in the hydrogen fuelled car but not in the petrol car, unless they were able to escape quickly.

"I would rather be near the hydrogen car."
Man

The women were of the same opinion.

The men's group also raised the question of what would happen if there was a crash where there was an escape of hydrogen and how this would affect the atmosphere. There was, however, an appreciation that an accidental release of any type of fuel has implications.

"Well you have got the issue of what happens when it goes into the environment and the crash issues but you have that with diesel and petrol cars now."
Man

Those who were less concerned about safety cited strong parallels with the dangers inherent in using petrol.

"I was just thinking if they had had a discussion group about a combustion engine run on petrol, what would it be like, how dangerous it would be and how it could explode, they would probably be saying very similar things to what we are saying now."
Man

"I mean, if this was about petrol and you asked someone, what about driving around with a really explosive fuel?"
Woman

"And fuelling it up on their own with a petrol nozzle, and they can wave it about, I think that's potentially a scary thing, I mean people can go in there smoking, but people just get used to it."
Woman

"If you have a pot of petrol on the table you would be very nervous about it. When it's in your car and you get it from the pump you don't really think about it."
Woman

The heat of the steam emitted from engines was queried with the expert but participants were reassured when they learned from the expert that the steam would be *"at the same temperature as the steam coming out of kettle but the actual temperature of the exhausts at the moment is a lot hotter than that"*. Moreover, the hydrogen fuelled buses have their exhausts on the roof so that the steam rises and this could be seen in the picture of the London bus used in the groups.

While the Hindenburgh disaster sounded a note of caution for some of the men, the women's view was:

"I think we've advanced a bit since then."
Woman

In conclusion, some participants believed:

"I think I will be for it definitely because I don't think the government will let it go ahead if it wasn't as safe as petrol."
Man

On the other hand:

"Well they [the government] *sponsored nuclear power development. I don't have that same faith in the government."*
Man

But then again:

"I don't think anything like that happens if it wasn't safe, 'cos there are so many pressure groups."
Man

The question of smell arose and the expert informed the groups that the HSE insists that gases must have a smell to alert people to leakages. The women quickly saw the parallel with natural gas where a smell is added before it can go on the market.

Importantly, we found that a reassuring factor for participants was the use of existing technology.

2.5 Cost

Cost was the primary consideration for participants when considering whether they would choose hydrogen as a fuel source personally. This was not only the cost of the hydrogen itself but also the cost of buying or converting machinery (such as cars or heating boilers) to run on hydrogen. Even for those more environmentally aware, cost was ultimately more important than the impact on the environment.

> *"I think its more an issue with cost..... I think if you went out to the streets and asked 2000 people, 70% of them would think of more of the cost than the environment. You are only thinking in the short term."*
> Woman

Grants for conversion of appliances, homes and cars were suggested, if the government wants to get people to switch to hydrogen. However, there was scepticism that once most people had converted, initially low prices for hydrogen would rise as a result of increased taxes.

> *"They will probably make it cheaper and give people tax breaks for doing it."*
> Man

> *"They will wait till we are all addicted to it and put the taxes up."*
> Woman

> *"I mean, give it a couple of years and the government will get their claws into it and then it's not going to be cheap."*
> Man

With respect to public transport, participants said that they would not use a hydrogen bus if it was more expensive than a standard bus, unless it was raining.

2.6 Environment

The women believed recent changes in the local weather conditions, such as last year's hot summer and recent heavy rainfall, to be demonstrations of global climate change, as the following discussion illustrates.

> *"We are so advanced in things more than before, but we are still using petrol, which is giving off things that are causing problems but by the time our children are having children I wonder what state we are going to be in. I hope we can find something that is better for the environment."*

> *"Something that is renewable, our fear is we are seeing it in perhaps the weather changes and what we were supposed to see in perhaps 20 years time we are seeing now with the rain, we don't know how much that has got to do with the ozone."*

> *"But it is a fear for my children I think."*

> Moderator: *"Does that concern you then?"*

"You seem to every day pick-up a paper and see more situations classed as natural disasters but we don't know if that is why."

Women also recognised that there could be benefits from a fuel that does not produce noxious fumes.

"I think the pollution side if they could prove its better 'cos these days pollution is a big thing, with people who suffer from asthma."
Woman

The men saw the environmental issues as:

"There are environmental issues with producing petrol and there will be with this [hydrogen] *too, the difference is it's going to be a different set of environmental issues.*
Man

The women were aware that everyone should *'do their bit'* with recycling and fuel conservation but they were also aware that this was difficult. It required some level of effort (such as taking things for recycling), some institutional changes (more facilities and incentives for recycling) and might even produce conflict with children (by, for example, limiting the number of televisions in a household). Hence they believed that:

"Just putting it [hydrogen fuel] *forward as an environmental thing isn't enough."*
Woman

Nevertheless, cost remained the major stumbling block in these participants' willingness to take-up the technology.

2.7 Production

2.7.1 Production methods

Once the production methods were explained, participants recognised that pollution would be removed from the point of use to the point of production. However, this was not necessarily seen as a completely good thing:

"It just seems to transfer the problem to the place where it's being produced."
Woman

The most favoured method of production was the biological methods involving algae and bacteria as these were thought to produce the lowest levels of pollutants. Participants, especially the women, thought that this line of research should be pursued.

"They use penicillin that came from mould in the first place. Although it sounds terrible, the end product is worth it."
Woman

> *"We have to move on, so we have to realise that are money has to go into research."*
> Woman

The production methods that are carbon neutral were also more attractive to participants than those that relied on conventional electricity production. There were some concerns about whether sufficient trees could be grown quickly enough, as not everyone immediately grasped the concept of coppicing.

> *"As long as for the wood they are burning they can reproduce it, they need to make sure the on-going tree planting continues to outweigh…."*
> Woman

There were also concerns that:

> *"You still have the burning though."*
> Woman

Sequestering the carbon dioxide produced during hydrogen production was thought to be an option to be considered because scientists may develop a way of dealing with it in the future.

> *"..we would hope the brains would move on and find another way forward."*
> Woman

Using renewable energy methods, such as wind farms, to produce hydrogen was also seen to be a good way forward.

The expert wanted to explore how participants felt about using nuclear power to produce hydrogen. Participants were not happy with a nuclear power option. Not only was it seen as unsafe, it was seen as an old technology.

> *"Are we really moving forward if we are using nuclear?"*
> Woman

Another woman felt that she did not know enough about nuclear power to comment and that she did not want to know more about nuclear power because *"it would scare most people"*. Nuclear power was not seen as environmentally friendly, unlike the renewable energy and bacterial production methods that had been described.

Both groups wanted to know what happened when fuel cells run out and how they are disposed of or recharged. They were reassured by the expert that these could be recycled.

2.7.2 Production plants

With respect to the location of production plants, participants said that if there was a proposal to locate a site near to their home they would want to know about emissions, safety, etc. just as with any other production plant. The women in particular saw nothing different about a hydrogen production plant from other industrial development. Some of the men, on the other hand, were concerned about the scale of the production plants, the sources of energy the plants would require and local pollution problems emanating form the plants.

> *"But what about the by-products from the factories that make the stuff?"*
> Man

2.7.3 By-products

Questions were asked about whether the production of water as a by-product would mean that the local atmosphere would be damper than it might otherwise be. In the second session, one man was concerned about what would happen to the oxygen left over from removing hydrogen from water. The expert reassured him that when released to produce energy, hydrogen would recombine with oxygen, thereby keeping a cycle going.

One participant however, considered that:

> *"The by-product is water and it's the worst of all the greenhouse gases."*
> Man

The expert explained in the second session that this would only be a problem if aeroplanes flew above a certain height. This is because, while water is a greenhouse gas in the upper levels of the atmosphere, at the level at which water would be produced as a by-product of using hydrogen fuel, there is little to worry about.

Learning that industry already produces hydrogen and that initial production would centre on existing sites using existing methods, appeared to reassure participants about safety and pollution during production.

2.8 Storage

Learning that hydrogen does not have a 'shelf life' and can therefore act as an energy store, was another point in its favour. This was especially true in the context of using wind power to produce energy that could be stored for periods when there was no wind.

2.9 Transportation

Some of the men were concerned about moving hydrogen around but others again identified parallels with things that already go on.

> *"Gas cylinders get transported around on the backs of lorries and they are under pressure, so I don't think I'd be that concerned."*
> Woman

While some of the men considered the impact of accidents during transportation, the women assumed that the fire brigade would be trained to deal with accidents.

2.10 Supply

The wider context against which this discussion took place should be borne in mind. Just before the first sessions there had been coverage in the media of the Venezuelan presidential vote and concerns about the future supply of oil from Venezuela. Obviously, the situation in Iraq was well known and the rising price of oil was featuring on national news.

Several aspects to the issue of power and fuel supply were identified. Firstly, there was the issue of the security of supply of oil and the level of world reserves. Secondly, there were issues related to consumers being able to access retail outlets for hydrogen.

Participants were aware of problems in the supply of petrol and the women highlighted our dependence on petrol as a society by citing the problems caused by the 'fuel crisis' (blockades of petrol refineries) in the autumn of 2000.

> *"..the petrol crisis we had, it was quite interesting with all the cars off the road. It made you realise how dependant we were."*
> Woman

> *"I am quite cynical about it* [hydrogen as a fuel source]. *Also, I think it has to do with where all the petrol and crude oil has come from, I think they want to cut as many links with the Middle East as possible because any way of not buying crude oil from the East, we won't be putting money into these countries."*
>
> Man

Participants had a general knowledge that petrol would not last for ever and that other sources of fuel are needed but were unsure of timescales involved.

> *"The fuels are going to run out, maybe not for 50 years but it is going to happen, just think about your children."*

> *"Its going to happen* [running out of fuel] *in their or their children's lifetime, I think that's just the scariest thing, like how the Arab world is with us now. I know you still need to use petrol but maybe you can use less, we don't now if they are going to say 'right you aren't going to have anymore'."*

The men raised the question of who would supply hydrogen to the consumer. Their first thoughts were gas companies such as British Gas, whom they assumed would monopolise the market. Once participants were aware that the big oil companies, such as BP and Shell, are involved in the development of hydrogen as a fuel source they realised how little they knew about the supply of oil. The involvement of these *"big concerns"* in the research reassured them.

> *"If the oil companies are involved it gives you a little more reassurance that it is going to be there long term. If they are researching into it and it's still going, I am really surprised by that."*
> Woman

> *"I suppose if petrol is running out they have to try an alternative."*
> Woman

Weaning people off their cars was seen to be very difficult to achieve, so finding alternative fuel sources was thought to be very important.

"..the car is so convenient, so many people just jump in the car for the slightest thing."
Woman

"If you need to get a couple of buses it's just hassle...It's the time factor."
Woman

If hydrogen is to be used as a major fuel source, consumers must have easy access to reliable sources or they will not use it.

"...the availability is an important factor."
Woman

As mentioned above, some participants knew people who had converted their cars to LP gas, especially taxis drivers. This was now a more feasible option as not only was it cheaper, but:

"You can get it [LP gas] *at Asda now."*
Woman

2.11 Usage

Some participants were surprised to learn that there are buses running using hydrogen fuel and that the car industry has long term research projects in the area. Some assumed that performance would be like traditional electric cars, little different from milk floats. Performance is important to women as well as men. The women said that they would expect the same performance or car manufacturers would *"never have entertained the idea"*.

We asked participants what they consider when buying a car as a way of eliciting how the use of hydrogen rather than petrol might feature in their decision-making process. Cost (value for money, purchase and running costs) and reliability were the two most important factors. Anything that needs regular charging or has distance limits would not sell to these groups.

"Basically they [cars] *have to last and they have to work."*
Man

These participants acknowledged that some people would consider environmental performance but not the majority.

Questions were asked about noise levels of hydrogen powered vehicles. Once it was explained that if hydrogen fuel is used to power an internal combustion engine noise levels would be the same as at present but with fuel cell technology noise levels would be reduced, participants had no further concerns. The expert who attended the second session raised safety concerns that had been voiced elsewhere about pedestrians being at risk if they could not hear vehicles coming. Participants realised this could be an issue but had not thought of it.

The women assumed that the change over to hydrogen power would be a gradual process, led by *"those who always have to have the latest thing"* and that people would have time to see that the fuel is safe and efficient before using it.

> *"The first thing I thought of is the explosion side of it but if people are using it and not afraid of using it...It's like anything new."*
> Woman

They thought that using public services, such as buses, to generate publicity would help to inform people about hydrogen and enable them to get used to it. They also believed that financial incentives would be needed to encourage and support people to move to hydrogen energy sources. Hence they identified the need for a lead from government. They suggested tax reductions on cars and fuel and grants for converting domestic boilers. Again they found parallels in moving people on to condensing boilers, the introduction of natural gas and the switching of television from analogue to digital. They also suggested putting hydrogen powered boilers into new homes and making new cars run on hydrogen.

Participants identified some groups, such as the elderly, for whom change might be threatening or difficult. Moreover, they believed that educating children about hydrogen would be a good way of disseminating information and reassuring people, as children can be used to educate their parents.

In contrast, there was some suspicion from the men about the current focus on public transport. Questions were raised about whether this was a way to force cars off the road. In a similar vein, there were also concerns about forcing people to buy more expensive hydrogen fuelled cars, rather than having their existing car converted and that only newer cars would be able to be converted. The involvement of commercial car manufacturers served to reassure these men that new products would be cost competitive. They were sure that car manufacturers would not invest in developing products using a technology that is too expensive for consumers to purchase. However, they were seen as a having a vested interest in making existing cars obsolete. The men recognised that hydrogen fuel will not solve congestion problems and this left some room for suspicion that the government would still use the tax system to pressurise people off the road.

There was some a belief that:

> *"We will get forced in to it anyway and won't have much of a say in it."*
> Man

By contrast with the women, some of the men had little understanding of the government's role in ensuring appropriate regulations are in place and that the UK attracts inward investment from international companies seeking to locate production plants. They tended to see the technology as being market led, driven by the private sector. Indeed, support from national politicians reassured some of the men but not others because politicians were seen to *"jump on bandwagons"* or disagree with each other *"because that's what they're supposed to do"*. Some felt that the scientific community needed to speak out in favour of hydrogen but others were sceptical of their involvement.

"Why trust them so much? It was trumpeted that nuclear power was safe and battery powered cars would save the day but they ran into problems. They do that with all sorts of technologies."
Man

Some men believed that persuading people to use hydrogen fuel will come down the "*the specs*" for the cars and value for money. But the expert was warned that vested interests from somewhere would oppose a hydrogen economy:

"Someone will set-up a group to say they don't like it."
Man

Participants were not given information about other forms of alternative energy. Nevertheless, wind power and biofuels were raised by the participants. The men felt that another technology might come along and replace hydrogen in the not too distant future. The expert told the group that there are a lot of alternatives to petrol in development but that hydrogen is the fuel that Wales can make itself, given its size and climate. Some of the men were aware of the development of biofuels and the expert explained that Brazil is looking at biofuels but that Wales does not have enough land or water to be self-sufficient in biofuels. However, because there are several ways of producing hydrogen, Wales could be self-sufficient.

2.12 Wales

Participants were informed by the moderator about current hydrogen projects in Wales. All were surprised, none was aware that hydrogen is being produced and used as a fuel in Wales. Neither was there an awareness that bus trials are taking place in a number of cities around the world, including London.

We asked participants how they felt about Wales being at the forefront of the development of hydrogen technology. Even those who were more concerned about safety issues thought *"it would be great"*. Participants thought that it would be good for tourism and for jobs.

"It would be exciting if Wales could produce it, whatever the method, so we could be self-sufficient, it would be a real boast for the economy."
Woman

"It will bring in more jobs, good politically, could raise the intellectually level of the country, could put us on the map."
Man

"It [hydrogen] *will be good because we could produce it ourselves."*
Women

2.13 Conclusions

Some of the men who took part in this project were very negative, far more so than we might have expected given other work on hydrogen fuel elsewhere in the world and on new technologies generally. Nevertheless, interestingly, both the men and the women said that they thought that the men would want to "*pull things apart and try to look for* *reasons"* and that *"women are more accepting"*. Women also thought that *"men don't seem to accept change quite so easily."* However, it should also be borne in mind that the men had more knowledge of hydrogen as a chemical and other studies have found that the better educated are more sceptical of scientific developments.

The two main concerns were found to be safety (both of use and in production) and cost. With respect to safety, the use of tried and tested technologies was reassuring and the women more often identified parallel situations that had gone well and this reassured them about hydrogen. Indeed, the men who were less concerned also referred to previous and current situations to reassure others in their group. Importantly, the photograph comparing two burning cars allayed many fears.

However, unless the technology is cost effective, in fact more cost effective than current technologies, participants would be reluctant to shift to hydrogen technology. This was also true for those who were more environmentally aware because cost remained paramount. Hence environmental arguments alone seem unlikely on the basis of these findings, to change fuel usage behaviour, except at the margins. Participants did, however, find this to be reassuring and something that makes hydrogen worthy of consideration. Indeed, bacteria and renewable energy sources were seen as the most desirable ways forward for hydrogen production.

At the end of the day:

> *"Most things work on a proof of a track record. So once the tests have been done and they have proved themselves, I think most people are going to go for it, it's all down to the way it's marketed."*
> Man

One of the women pointed out that the time for reflection between the two sessions, separately from the extra information presented in the second session, had enabled a different perspective. Any information strategy must therefore realise that initial reactions may be hostile. As one participants said *"it's like with anything, people need time to get used to it."*

The idea that Wales could become self-sufficient and a leader in this field aroused national pride.

3. Public Communication Strategy

3.1 *Introduction*

This section explores the issues that might be debated with the public to raise awareness of the potential of hydrogen fuel as a substitute for fossil fuels. We begin by analysing the potential threats for hydrogen fuel identified by the participants and by exploring any parallels with the GM food and crops issues. GM technology are being rejected by many British consumers. This has raised concerns in other fields where new technologies are being developed that they too might be rejected by the public.

From this analysis we have identified the main objections to hydrogen that UoG, working with others, should address.

3.2 *Threats to hydrogen as a fuel source*

From this project we have identified the following possible threats to the success of hydrogen as an alternative fuel:

Cost – if it is too expensive for the general public to buy the fuel or the machinery that can use the fuel.

Safety – while some people identify hydrogen fuel with hydrogen bombs, not all do. A major safety incident before hydrogen is established in the fuel market would be an obstacle, otherwise the parallel with the potential dangers of petrol and gas serves to reassure, as did the use of existing (tried and tested) technologies.

Production – if production methods increase, or do not reduce, CO_2 levels, people would be less favourable. It might be on these grounds that pressure groups develop an 'anti' campaign. Moreover, the local pollution associated with production plants, including those that use nuclear technology, might make it difficult to produce hydrogen in commercial quantities in Wales.

Alternatives – Biofuels might appear more favourable than hydrogen but participants were not given information about competitive alternative sources, except where they raised it themselves.

3.3 *The GM crops parallel*

The main reasons for public rejection of GM crops have been identified as:

- health concerns on the impact of eating GM food;
- environmental concerns about the spread of GM pollen and cross-contamination;
- lack of choice (products were not labelled);
- lack of perceived benefits to consumers;
- control of the food chain by (US) big business, especially in the developing world;
- corporate profits; and
- the BSE experience and the lack of Government openness.

In this small project on attitudes to hydrogen fuel we found parallels with these concerns.

3.4 *The main issues to be addressed in dialogue with the public about hydrogen as a fuel source*

GM food and crops	Hydrogen fuel
• health concerns about the impact of eating GM food	• safety at point of use
• environmental concerns about the spread of GM pollen and cross-contamination	• emissions seen to be moved from point of use to point of production
• lack of choice (products were not labelled)	• while a gradual transition was assumed, meaning choice in the short term, being compelled to use hydrogen was rejected because of costs of transferring
• lack of perceived benefits to consumers	• need to be aware of, and believe in, shortage of oil reserves worldwide and see global climate change as more immediate
• control of the food chain by (US) big business, especially in the developing world	• control by big business seen as reassuring (they would not invest in something they cannot sell because of price)
• corporate profits	• car manufacturers seen to benefit from consumers having to replace vehicles
• the BSE experience and the lack of Government openness	• some suspicion about ulterior motives in removing/reducing dependence on the Middle East and reducing congestion by reducing car use given the current focus on hydrogen fuelled buses

Some of these concerns are more easily addressed than others. For example, the safety at point of use question was easily resolved by the photograph of the two burning cars (see annex 6). We see the main issues as relating to production with respect to:

- the methods of production;
- the safety of production plants;
- emissions from production plants and their visual impact on the landscape;
- the role of Government/politics;
- the role of big business; and
- the benefits of hydrogen as against other potential energy sources.

The other main issues are cost and safety at the point of use, both of which can be addressed fairly easily.

3.5 *Ideas for dialogue projects*

3.5.1 Exhibition and public meetings

An exhibition that travels to sites such as libraries, schools, leisure centres, museums, art galleries, shopping centres, public foyers, etc. could be developed. Technical staff will need to be available much of the time to provide more in-depth explanations, to listen to people's concerns and record their questions. Exhibitions could be supported by local meetings. Such meetings could be open to all comers or set out to target and incentivise specific groups. In running such meetings the important things to bear in mind are:

- People are more likely to speak in small groups of people similar to themselves;
- Having people with different points of view can stimulate a wider debate;
- Venues are important – a university is not somewhere most people have ever been, neither are town halls or four/five star hotels but public halls and 3 star hotels are good venues;
- Facilitators should listen to the points raised and respond by enabling the participants concerns to be further explored. This does not need to turn into a question and answer sessions.

For further information on running and organising such events see:

"Partnership for Public Awareness – Good practice guide", People Science & Policy Ltd, Engineering and Physical Sciences Research Council, June 2003

and

"Dialogue with the public: Practical guidelines", People Science & Policy Ltd., Research Councils UK, August 2002.

3.5.2 Dialogue with business and the public

Another option to consider would be events that target potential investors in, and manufacturers of, hydrogen fuel. This might involve demonstration projects, posters, talks and debates. Such high profile events, with international attendance could be used to generate wider publicity and may well attract the support of Government keen to promote inward investment. There might also be a public exhibition with explainers as an addition to this type of event.

To reach the widest audience the Hydrogen Research Unit at UoG should work with the university press officer to get stories in to the local media. These stories will need to be based around 'news', such as new developments or research findings, or even large international meetings held in Wales on the topic. Visits from large companies that are household names, seeking to invest in the region, would also attract media attention. Even the release of the findings from this research could serve to attract media attention and form the centre of a piece in the *"Western Mail"*. This is a long term and opportunistic strategy as it relies on 'happenings' that will catch the media's attention.

3.5.3 Demonstrations and open days

Organisations currently producing hydrogen fuel or researching new or more cost effective ways of producing hydrogen, could run open days and demonstration projects for the public. Such events could also be used to stimulate press interest, especially locally. These events should be interactive, that is, enable the public to question and give their views. They should also be open in the evening and at a weekend to ensure that those in work during the day can attend and possibly bring their children.

3.5.4 Alternative energy event

The biggest threat to hydrogen as a future fuel source might be other alternative energy sources, which might be more cost effective, more energy efficient or more quickly available. Hence a public event that involves the public in assessing the alternatives (including hydrogen) could provide interesting insights into the way forward. The risk is that hydrogen is not seen as a preferred option by the public in such a comparison.

3.5.5 Further research

Lastly, we suggest that there is scope for a larger research project in Wales on the public's perception of hydrogen as a fuel source. We suggest that a telephone survey of a nationally representative sample of 1,000 adults, lasting about 10 minutes, could yield important data on the extent of awareness, the proportion of the population who hold negative images of hydrogen and the relative importance of the concerns identified in this project, especially the issues of cost and environment. It would also serve to provide more precise data on the differences between men and women and different age and socio-economic groups. In particular, the rural/urban divide needs to be explored given the recognition that pollution could merely be displaced from the point of use (towns and cities) to the point of production (more rural areas).

Such surveys can be used to generate publicity.

3.6 Raising funds for dialogue

To engage with people on a more individual level UoG might consider an application to Sciencewise, the new grants scheme funded by the Office of Science and Technology (OST). This scheme requires matched funding, which must not come from public sector sources. Hence UoG would need to have support from the petro-chemical and/or car manufacturing industries before submitting an application, although funding can be in-kind. The closing date for the first round of Sciencewise applications is 15 November 2004. It is not clear yet whether there will be a second round.

Other sources of funding might be the European Union, the Welsh Assembly, the Engineering and Physical Sciences Research Council and the previously mentioned industries.

3.7 Conclusion

Any project that sets out to engage the public with hydrogen fuel must provide information about the cost, safety and production of the fuel. We have assessed the biggest threats to the future of hydrogen fuel to be mainly related to production, safety at the point of use, cost and performance against the alternatives. However, some participants were sceptical of politicians, while others were sceptical of scientists, hence we recommend that any event includes a spread of experts.

We have made some suggestions for projects that UoG could develop as dialogue/communication activities to engage with the public. All must use illustrations as visuals made a clear impact on views in the reconvened sessions.

Annex 1 Recruitment Questionnaire

Cardiff Briefing:

We want to recruit two groups:

- Group 1: 8 men aged 25-55, mixed social grade
- Group 2: 8 women aged 25-55, mixed social grade

The first groups will take place on 13 September with the reconvened groups on 22 September. We want a good cross-section of people.

Only recruit people who can attend both groups. The incentive is £40 per session per person.

Introduction

Hello my name is... and I work for...... We are recruiting people to take part in some research looking at different sources of energy. Could you spare me a few minutes to answer some questions please?

Q1	**Do you or any of your close relatives work in any of the following occupations?**		
	Energy industry	1	CLOSE
	Market research	2	CLOSE
	Journalism	3	CLOSE
	Public relations	4	CLOSE
	Marketing	5	CLOSE
	Teaching	6	CONTINUE
	Manual Labour	7	CONTINUE
	Other	8	CONTINUE
Q2	**Gender**		
	Male	1	Refer to quota
	Female	2	Refer to quota
Q3	**What was your age on your last birthday?**		
	<25	1	CLOSE
	25-55	2	CONTINUE
	>55	3	CLOSE
Q4a	**Are you...**		
	Working full time	1	CONTINUE, go to Q4b
	Working part-time	2	CONTINUE, go to Q4b
	Retired/not working	3	CONTINUE, go to Q4b
	Unemployed	4	CODE AS E
	Student	5	CODE AS C1
Q4b	**Job Title (WRITE IN)**		
Q4c	**Job Description (WRITE IN)**		
Q4d	**Size of Company (WRITE IN)**		
Q4e	**Qualifications (WRITE IN)**		
Q4f	**How many people are you responsible for? (WRITE IN)**		
Q4g	**CODE SOCIAL GRADE**		
	A	1	
	B	2	

	C1	3	
	C2	4	
	D	5	
	E	6	
Q5	**Are you or have you ever been a member of an Environmental Group?**		
	Yes	1	CLOSE
	No	2	CONTINUE
Q6a	**Have you attended a group discussion or depth interview within:**		
	The last 6 months	1	CLOSE
	The last two years	2	GO TO Q6b
	More than 2 years ago	3	GO TO Q6c
	Never attended ONE	4	RECRUIT
Q6b	**How many group discussions/depth interviews have you been to in the last 2 years? (I.e. 6 months - 2 years ago)**		
	1 or 2	1	GO TO Q6c
	More than 3	2	CLOSE
Q6c	**What was the subject of the discussion group(s)/depths you took part in the past?** **(WRITE IN SUBJECT MATTER AND APPROX - WHEN IT WAS FOR EACH OCCASION).**		
	IF ABOUT ENERGY - CLOSE. THIS IS VERY IMPORTANT. THE RESPONDENT MUST NEVER HAVE PARTICIPATED IN A DISCUSSION ON THE SAME SUBJECT. OTHERWISE RECRUIT.		
	NB: If you have any queries at all, please call your Manager • At least half of each group/set of depths must be **brand new** recruits. • The remaining half can have attended up to a maximum of 2 groups/depths in the last 2 years (i.e. 6 months -2 years ago) • **None** to have attended any group/depths in **last 6 months** • **None ever** to have attended a group/depths on the same subject matter (see QI) • All should be able to speak fluent English		
	Important: Never recruit friends or members of the same family.		

Annex 2 References

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Annex 3 Topic Guide - Session 1

Aim of 1st session

To gain initial perceptions of hydrogen, examine what people know about it, what they think about hydrogen as an alternative to other fuel sources in vehicles. Introduce methods of production, storage and use, and the concept of the "hydrogen economy". Leave with handouts.

NB Hydrogen can be used as a more general energy source but this research concentrates on its use as a fuel source in vehicles.

Introduction

Thank everyone for coming.

	Introduce self
	Introduce PSP and independence from the client
	Introduce anyone else who is observing or helping
	Has anyone been to anything like this before?
	I have here a list of things I'd like to cover but really want to hear your views on the issues we'll be introducing.
	There are no right or wrong answers. Everyone is entitled to their own view, so I'd like to hear from everyone because everyone's view is valid.
	You don't have to answer all of the questions.
	You are free to leave before the end of the session, if you wish.
	I would like to tape record the discussions, just to save me taking notes, so I can listen to what you're all saying.
	No one will be identified in the report. All the information will be collected together and anonymised.
	We are running another reconvened session with women/men on this project as well.
	Is everyone happy for me to record the session?
	SWITCH ON TAPE AND MIKE
	The project is sponsored by the University of Glamorgan.
	I work for an independent company called People Science & Policy Ltd and I am independent of the university.
	Introduce the project – I will tell you more about the project and what it's about but I'd like to get you first impressions on a few things first, so please bear with me for a little while.
	The report will be published and you'll be able to access it on the university website at www.glam.ac.uk
	Standard warm up round the room of introductions

Issues to cover

Hydrogen

Safety – image of hydrogen
Awareness/concern generated by Hindenberg disaster/zeppelins
Awareness/concern generated by hydrogen bomb
Knowledge/awareness of hydrogen as an energy source
Knowledge/awareness of hydrogen as fuel source/ fuel cells
Knowledge/awareness of hydrogen powered vehicles (cars and buses)
Perceived safety – risk and hazard

Start by getting reactions to the word 'hydrogen'. Brain storm using flip chart. What does it mean to people? What associations does it conjure up? Probe specifically for any safety concerns.

Using pre-prepared flip chart reveal and read out: 'Buses in Cardiff to use hydrogen as fuel'. What would you think if you saw this headline in the local paper?

Who would travel on these buses? Who wouldn't? Why?

Get first thoughts and clarify if from those who have or haven't heard of using hydrogen as a fuel. What image does it conjure-up (possible extremes are explosive as in rockets or quiet as in fuel cell electric vehicles) Brain storm associations. Use flip chart to list positive and negative associations. Probe for negative associations associated with explosions, nuclear, zeppelins (NB Hydrogen was not a fuel in this instance). Probe for positive associations associated with no pollution, clean air, multiple methods of production. Identify whether thought to be more or less expensive than current fuel sources.

Explain as necessary that research is being done to develop hydrogen powered vehicles around the world, including at the University of Glamorgan. Hydrogen powered buses in existence, London, Germany, Iceland, Australia. Why do people think this is?
[USE PHOTO OF HYDROGEN BUS]

For those that have heard of it: probe – where heard, how heard of it, what heard/known. Why it's being done.

Would anyone buy a hydrogen powered car? Who wouldn't? Why? [who would? Why?]

Explore car buying behaviour.

Vehicle purchasing decision factors:

(This is designed to explore concerns)

able to drive?
likelihood of purchasing NEW car, as against second hand
role in decision on new car, if any
cost – fuel and vehicle

safety
convenience – recharging/fuel access
environmental impact
performance
driving range
comfort/vibration
fuel consumption
noise
reliability
satisfaction with current vehicle
price
performance of alternative energy vehicles
driving range of alternative energy vehicles
recharging/refuelling of alternative energy vehicles

Lead into energy issues.

Energy

security of supply
environment
alternative energy supplies

What do you think about the issues there are at the moment around the supply of energy? Probe for what is known unprompted – then prompt: e.g. rising oil prices, instability in the Gulf, instability in Venezuela, problems of Russian oil industry, Equatorial Guinea coup, the need to buy gas from abroad with North Sea oil running out, climate change - global warming.

Prompt: What about alternative energy sources? Make a list of the different types of fuel sources. Brain storm with flip chart.

Image of different fuel types. What do people think about using different types of fuel? Reasons for these views. Pick out ones on the list. Personal experience of using alternative fuel sources.

Move on to views on environmentalism.

Environment

attitudes to environment and environmental issues

This is important because those who are less environmentally concerned have different attitudes to many other relevant issues from those who are more environmentally concerned.

Issues around storage, transportation and access

Get first reactions on need to transport hydrogen so that people can use it in their vehicles. What do people think would happen if there was an accident? Is it safer than petrol? Leads into more technical description of hydrogen production.

Hydrogen production

Just so everyone knows, let me explain how hydrogen fuel is generated. Hydrogen is not like coal or natural gas, it doesn't already exist in a useful form. It has to be made, which means that raw materials are needed and energy is needed to extract the hydrogen. Hydrogen is present in many different forms, so there are several different ways of generating hydrogen that can then be used as a fuel.

FOSSIL FUEL ROUTES

Fossil fuels such as oil, coal and natural gas are mostly made up of carbon and hydrogen and when we think about burning them in a traditional sense we are breaking up their structures to release energy. It is also possible to break up the structures in a more controlled way to release the hydrogen, which can then be collected as a fuel. Oxygen and steam are reacted with fossil fuels to release hydrogen.

What are the strengths and weaknesses of this approach?

[FOR FACILITATOR] This is a commercially available process, which is of interest to countries with large coal resources. It relies on non-renewable resources and releases CO2 a major greenhouse gas as a by-product of production.

FROM BIOMASS

Biomass, for example coppicing from woodland, is also mostly made up of carbon and hydrogen and can be burnt in a similar way to fossil fuels. It is also possible to break up the structures in a more controlled way to release the hydrogen, which can then be collected as a fuel. Either oxygen and steam can be reacted with biomass to release hydrogen or biomass can be heated without oxygen present to produce hydrogen by a process called gasification.

What are the strengths and weaknesses of this approach?

[FOR FACILITATOR] These are commercially available processes. Using renewable resources means that even though CO2 is released, there is not a net increase of CO2 as it will be absorbed by the biomass being grown to replace that used to produce hydrogen.

WATER SPLITTING

Water is made up of hydrogen and oxygen and electricity can be used to split the water into its component gases.

What are the strengths and weaknesses of this approach?

[FOR FACILITATOR] This is a proven technology that has been in use for over 80 years. However, it is only used on a large scale when there is a supply of cheap electricity available (for example hydroelectric power). If the electricity is from a renewable supply then this process will not release CO2.

BIOLOGICAL METHODS

Some types of algae and bacteria can produce hydrogen as a by-product of their growth.

What are the strengths and weaknesses of this approach?

[FOR FACILITATOR] These technologies are currently only at the R&D stage and cannot therefore provide commercial quantities of hydrogen.

Issues around production

Safety
Environmental

Do any of the production methods raise concerns at all – environmental, safety

Issues around storage, transportation and access

Get first reactions on need to transport hydrogen.
What about when it's being moved around?

Need to then explain about transportation, need for appropriate containers.

Hydrogen has the highest energy on a weight for weight basis of any substance, but it is very light, so it has a very low amount of energy for a given volume, this means that hydrogen has to be stored and transported at high pressure to make it viable to use as a fuel.

The Hydrogen Economy

Can you imagine a situation where all energy is produced using hydrogen?
What would be the limitations of this?

Further information

What is required, why, for next session?
Give out handouts and any websites or other places to look for information

Annex 4 Topic Guide – Session 2

Aim of 2nd session:

To answer questions raised in first session
To explore concerns in more depth and the impact of more information
To identify key pieces of information that enable discussion

Introduction

Welcome everyone back and introduce Samantha

Warm-up

Go round getting thoughts since last week one by one and any action looking for extra information, questions material gave rise to, etc.
Samantha to answer questions from last week and any follow-ons that arise

Main session

Main issues to follow-up after more information:

- Technical questions perception of hydrogen as a 'material'
- Safety concerns about use
- Concerns about production (not covered in the women's group, so need to raise this)
- Economics of a hydrogen economy
- Control of supply/reasons for developing hydrogen as an alternative fuel

Closure

Thank people for coming. Inform them what will happen with the findings. A strategy will be devised for informing people about hydrogen as a potential fuel source. It has been very important to identify from these groups they key issues people want to know about.

Annex 5 Self Completion Questionnaire

Public Attitudes to Hydrogen Fuel

Q1 **Please write your name here**

____

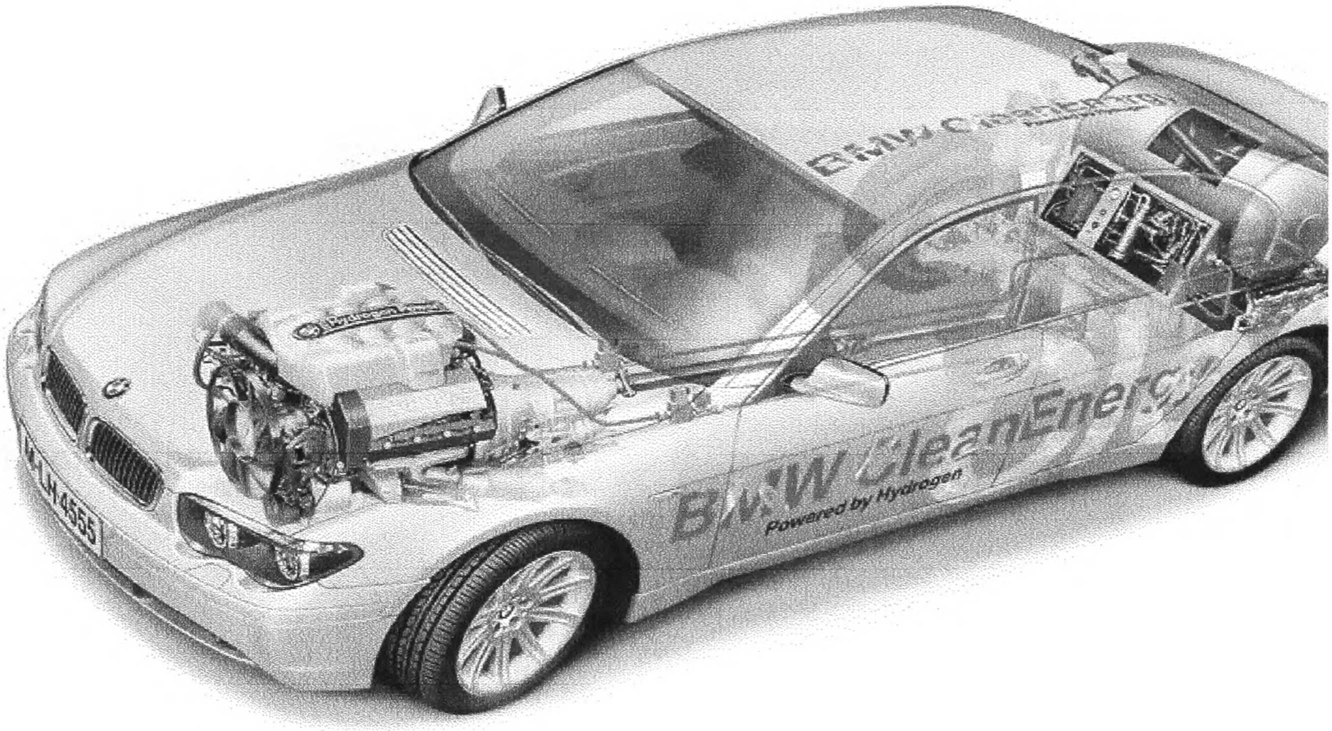
Q2 **Please say whether you agree strongly, agree, neither agree not disagree, disagree or disagree strongly with each of the following statements**

	Agree strongly	*Agree*	*Nether agree nor disagree*	*Disagree*	*Disagree strongly*
I am not interested in science and I don't see why I should be	☐	☐	☐	☐	☐
Because of science engineering and technology there will more opportunities for the next generation	☐	☐	☐	☐	☐
When I buy something like a washing machine, value for money is the MOST important thing I consider	☐	☐	☐	☐	☐
Science and technology are making our lives healthier, easier and more comfortable	☐	☐	☐	☐	☐
In general scientists want to make life better for the average person	☐	☐	☐	☐	☐
It is important to know about science in my daily life	☐	☐	☐	☐	☐
The more I know about science the more worried I am	☐	☐	☐	☐	☐
It is important to look after the environment	☐	☐	☐	☐	☐
I cannot follow developments in science and technology because the speed of developments is too fast	☐	☐	☐	☐	☐
Science is getting out of control and there is nothing we can do to stop it	☐	☐	☐	☐	☐
The speed of development in science and technology means that it cannot be properly controlled by the Government	☐	☐	☐	☐	☐
People make too much of environmental concerns	☐	☐	☐	☐	☐

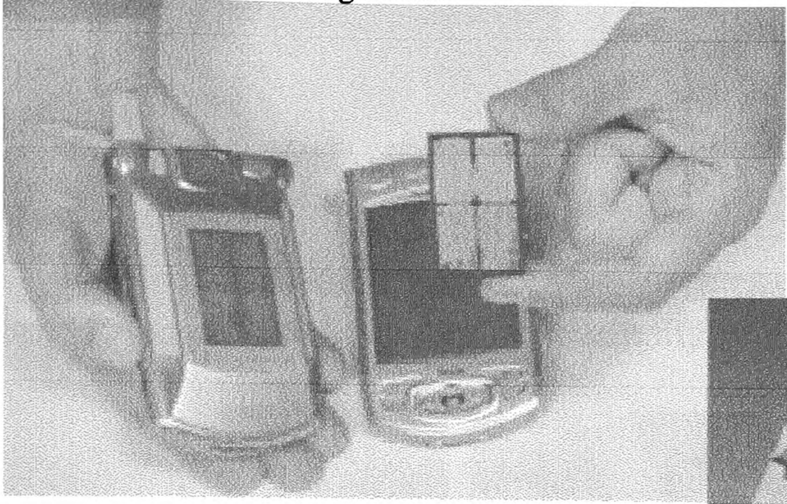
Thank you very much for your help

Annex 6 – Illustrations Used in Second Sessions

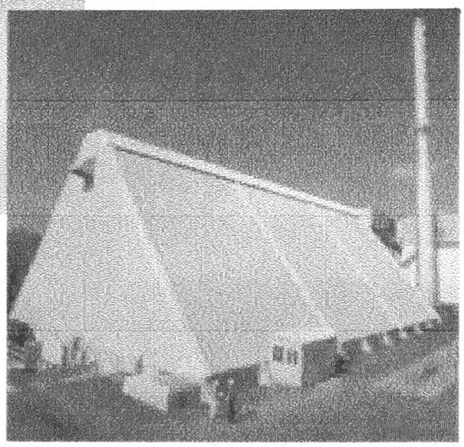
BMW prototype using liquid hydrogen



Illustrating that fuel cells can be small enough to fit into a mobile phone or large enough to generate power on a large scale.

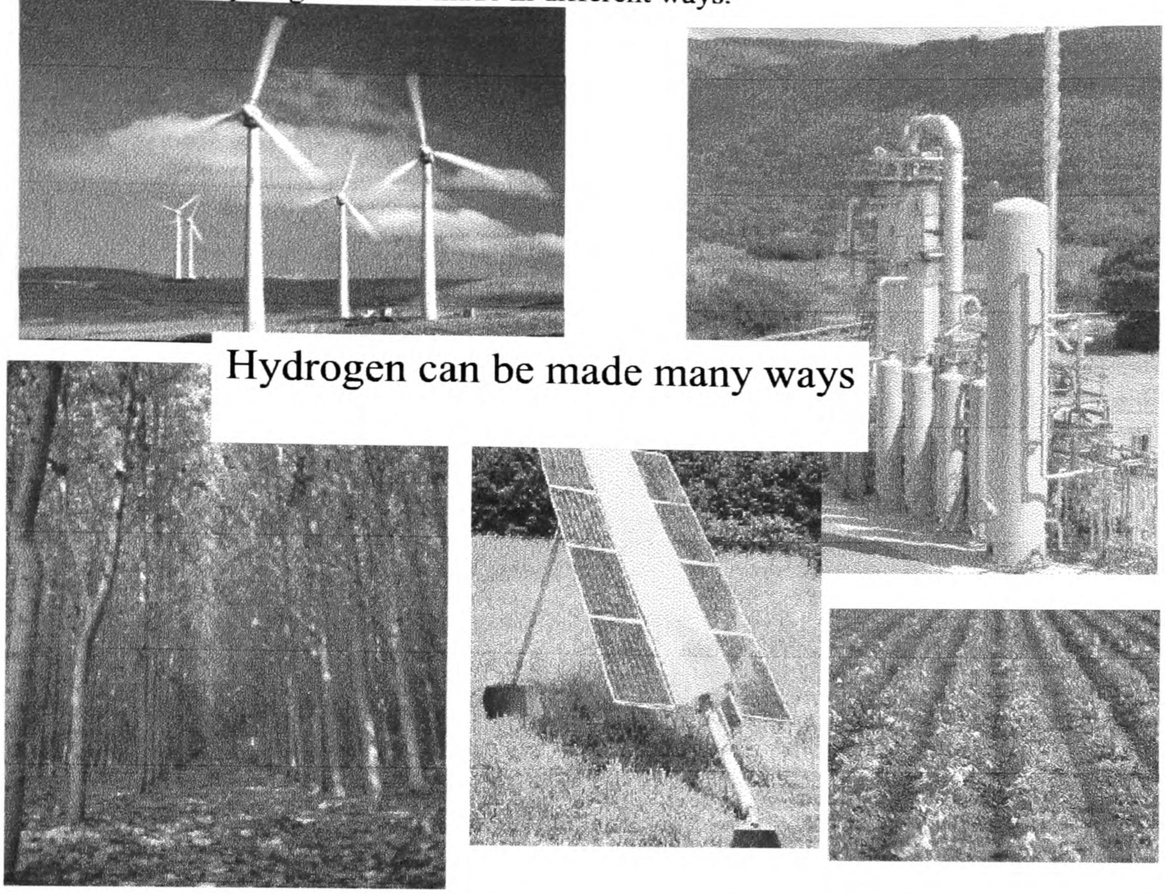


Fuel Cells come in all sizes

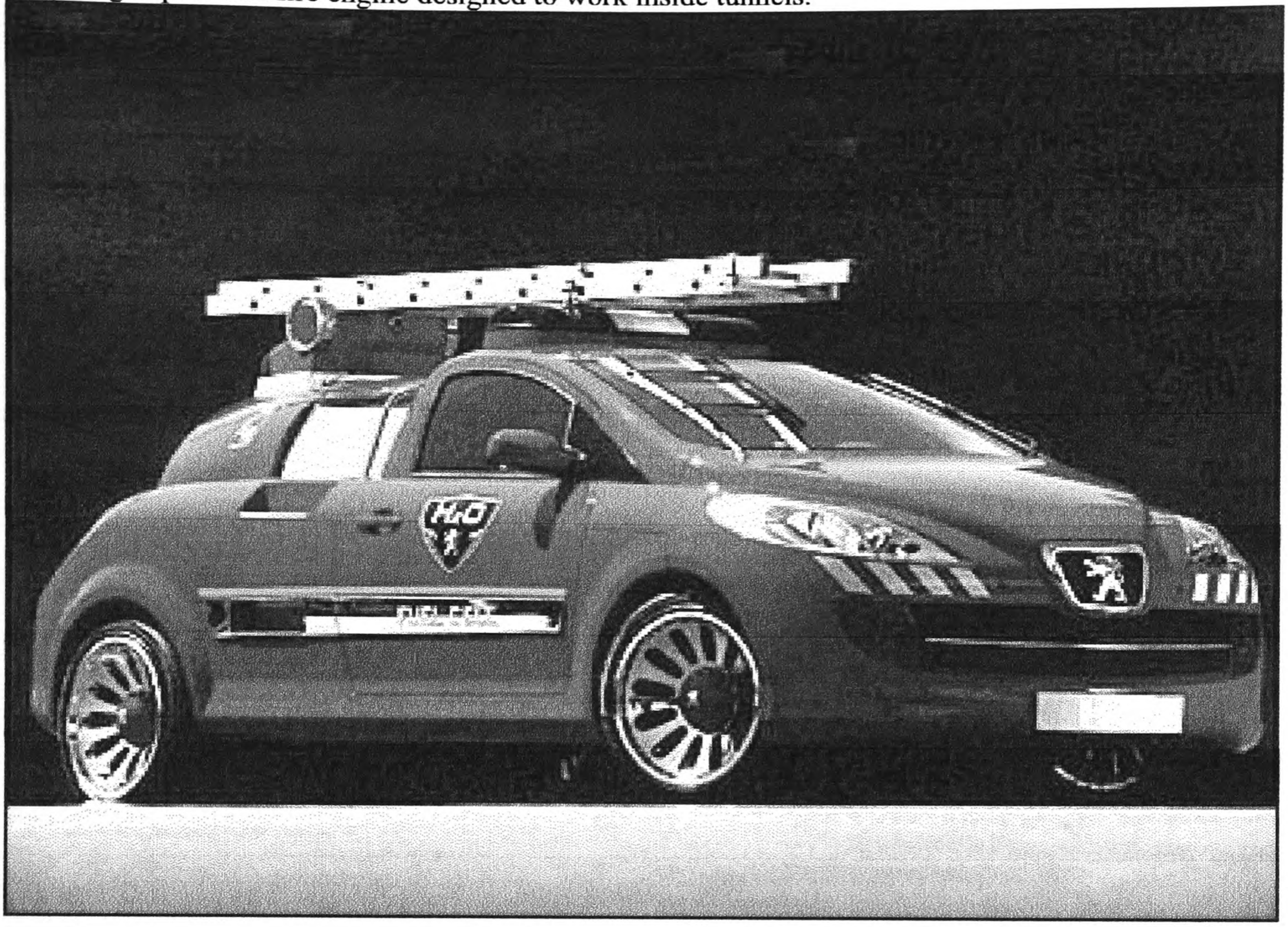


Pinetree Power Plant, Fitchburg, MA
Source: www.neonrg.org

Illustrating that hydrogen can be made in different ways.



A hydrogen powered fire engine designed to work inside tunnels.



This photograph illustrates what happens when a hole is pierced in the fuel tank and the emissions from the tank set alight.

Appendix 6 – Office of Science and Technology briefing notes on the hydrogen economy

Parliamentary Office of
Science and Technology

postnote

October 2002 Number 186

PROSPECTS FOR A HYDROGEN ECONOMY

There is increasing interest in the use of hydrogen as the basis for an energy system with low carbon dioxide emissions. Hydrogen could be used as a fuel for road transport, distributed heat and power generation, and for energy storage. This has led to discussion of a 'hydrogen economy' – widespread and diverse production and use of hydrogen. This briefing outlines the basis of interest in hydrogen and examines technologies for its production, handling and use. Policy issues surrounding technology and market development of hydrogen are also considered.

Background

Hydrogen is a commonly used industrial gas, which is produced for use in the chemical and other industries, and in refineries for fuel processing. The idea of using hydrogen for energy is not new. It has been used both industrially, domestically (town gas, used in the UK until the 1950s, comprised 50% hydrogen) and as rocket fuel. Interest in hydrogen as a vehicle fuel dates back to the 1800s, but heightened during the oil crises of the 1970s and with technological advances in the 1980s.

Current interest in hydrogen stems from environmental and energy policy concerns including global climate change, local air quality, noise and security of energy supply, together with breakthroughs in fuel cell technology (see page 2). Hydrogen can provide power with minimal air pollutant and zero carbon dioxide emissions at the point of use. For instance the Energy Saving Trust (EST)[1] has referred to the use of hydrogen in fuel cell vehicles as *'the most promising option for zero carbon road transport'*. Also, because there are many possible production routes and uses for hydrogen, it could enhance security of energy supplies.

An energy carrier

Unlike oil, gas and coal, hydrogen does not exist in large quantities in nature in a useful form. Like electricity, it is an 'energy carrier', which must be produced using energy from another source. Hydrogen has an advantage over electricity, however, in that it can be stored more easily. This allows its use as a vehicle fuel, for electricity and heat generation and as a storage medium for electricity generated from intermittent renewable sources.

Production

Hydrogen can be produced from a wide range of sources by a number of different routes (see box on page 2). These include:

- from hydrocarbons such as coal, oil and natural gas
- from biomass and wastes
- by electrolysis of water, using electricity produced from fossil fuels, nuclear, or renewable energy.

While hydrogen has minimal environmental effects where it is used, there may be impacts associated with its production. For instance, production of hydrogen from fossil fuels leads to carbon dioxide (CO_2) emissions, the principal cause of global climate change, and also to resource depletion. The overall CO_2 emissions may be lower than if conventional technologies (such as a petrol internal combustion engine) were used[2], and there are also lower emissions of local air pollutants.

It may be possible to capture and store the CO_2 produced in biological or geological sinks, such as forests or underground reservoirs. However, CO_2 emissions would be negligible if hydrogen were produced by electrolysis using nuclear energy, or renewable energy sources.

Hydrogen production technologies

- **Steam reforming** – this is the most common method Here, a hydrocarbon gas, often methane, is mixed with steam at a high temperature and pressure, in the presence of a catalyst, to produce hydrogen and carbon dioxide. The hydrocarbon gas can also be produced from biomass products by heating to high temperatures with little oxygen present (gasification).
- **Partial oxidation** – hydrogen can be produced by reacting heavier hydrocarbons such as oil, coal, and some biomass products, with oxygen and steam. This is a commercially available process and is of interest for countries with large coal resources.
- **Electrolysis** – an electric current is used to split water into hydrogen and oxygen. Alkaline electrolysis, the most common form, has been used industrially for over 80 years, but is now used on a large scale only where cheap electricity (e.g. from hydroelectric schemes) is available. There is significant interest in very small scale (e.g. domestic) electrolysers.
- **Biological methods** – several types of algae and bacteria can produce hydrogen by photosynthesis or by fermentation. Some methods may have commercial potential, but most are at the R&D stage.
- **More prospective technologies** – these include photoelectrolysis, the use of a solar cell that splits water directly, without use of electricity.

Hydrogen storage technologies

Compressed gas
Compressed hydrogen is generally stored in cylindrical tanks at pressures of around 200 bar (around 200 times atmospheric pressure). Low pressure storage, either in tanks or underground, can be used for very large volumes. On-board storage systems for vehicles have been demonstrated at pressures of up to 700 bar, using tanks made from composite materials. Compressed storage is the cheapest method, however storage density is low. Higher storage pressures increase the storage density, but also the costs of the system and the safety requirements.

Liquid hydrogen
Hydrogen can be stored as a liquid at -253 °C in insulated pressure vessels. The liquefaction process itself is energy intensive, but liquid hydrogen has a very high energy density, over three times that of petrol. Highly insulated tanks are needed to minimise evaporation, and these can make on-board liquid storage relatively bulky and heavy.

Chemical storage
Metal hydrides are metal alloys that can store hydrogen within their chemical structure. Hydrogen is bonded to the surface of small particles of the material and is only released when heat is supplied. Hydrogen can also be stored within carbon materials and in the form of liquid hydrides.

Storage and distribution

Hydrogen contains more energy on a weight for weight basis than any other substance. However it is also the lightest chemical element, and so has very low energy per unit volume. For example, at 200 times atmospheric pressure, one litre of natural gas contains 5 times more energy than a litre of gaseous hydrogen. The box opposite outlines a number of methods for storing a useful amount of energy in a small volume, e.g. in a vehicle. The most suitable storage method depends on factors including the volume to be stored, the storage time, space restrictions and end-use requirements. For example, in buses, compressed hydrogen can be stored in tanks on the roof.

Hydrogen stored by any of the methods mentioned in the box opposite can be transported by road, rail or sea. Compressed hydrogen can be transported via dedicated pipelines. There has also been discussion of mixing hydrogen into natural gas in the pipeline network.

To refuel vehicles with hydrogen, new dispensing technology will be required, to which consumers will need to adapt. Both gaseous and liquid hydrogen refuelling are sufficiently developed that refuelling could take place in a few minutes, with no leakage. The world's first public liquid hydrogen filling station uses a robotic dispenser, without the driver having to leave the car.

Use

Hydrogen can be used to provide electricity and heat either through use in a fuel cell (see box on page 3) or through combustion. A fuel cell is a device similar to a continuously recharged battery, which generates electricity by combining hydrogen with oxygen from the air. The only byproduct is water. Hydrogen fuel cells are silent, have no moving parts and produce no air pollutants.

Fuel cells can be used to provide electricity on a small scale for homes and businesses, and can be included in combined heat and power (CHP) schemes. Stationary systems have fewer constraints on storage space and system weight than vehicle systems and require less infrastructure development.

For transport, hydrogen can be burned in an internal combustion engine (ICE), in the same way as petrol or natural gas. BMW currently uses this technology to power a fleet of demonstration vehicles. This produces water as the main byproduct, but also small amounts of oxides of nitrogen, an air pollutant. Dual fuel ICE vehicles have been produced to run on both hydrogen and petrol.

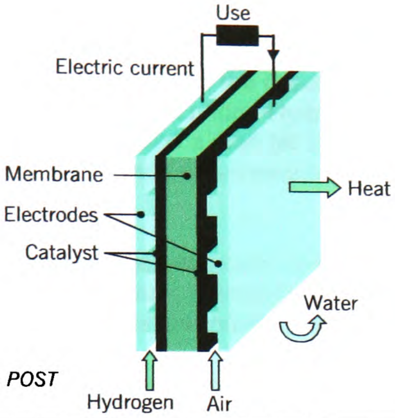
Hydrogen can also be used to power fuel cell vehicles. Using hydrogen in fuel cells is more efficient than combustion, with efficiencies of up to 45%, compared with up to 25% for a dual fuel ICE. Therefore a fuel cell car could travel over twice as far as a dual fuel ICE car on the same amount of hydrogen. Hydrogen ICE and fuel cell cars are currently at the demonstration stage (see box on page 3). Eight major car manufacturers are planning to introduce fuel cell cars by 2004-5. However, there are still issues of cost, reliability and lifetime, such that fuel cell cars are not expected to reach mass markets until after 2015. As there is considerable experience with ICEs, some consider that they may be important in the interim.

Safety

Like most other fuels, hydrogen is flammable, and potentially hazardous if handled incorrectly. It is no more hazardous than other fuels, but has different properties which must be understood in order to store, transport and use it safely (see box on page 3).

Fuel cells

A fuel cell combines hydrogen with oxygen from the air in a chemical reaction, producing electricity. One type of fuel cell for transport, (the *proton exchange membrane* fuel cell) consists of two electrodes, separated by a membrane. Many fuel cells are connected to provide the power needed.



Source: POST

Current projects

Projects demonstrating the use of hydrogen as a vehicle fuel are in operation worldwide. For example, the **Munich Airport Hydrogen Project**, opened in 1999, supplies hydrogen to cars and airport buses. The **California Fuel Cell Partnership**, also established in 1999, comprises 28 government and industry groups, testing and promoting fuel cell vehicles. The EU **Clean Urban Transport for Europe** project will provide fuel cell buses in 10 European cities in 2003, including 3 in London. In the UK, projects include a stationary hydrogen fuel cell used in Woking to provide heat, power, cooling and clean water for a leisure complex, with hydrogen generated by reforming of natural gas. The **Urban Solar Hydrogen Economy Realisation Project** in Cambridge will use electricity from a photovoltaic system to produce hydrogen for buses. **Iceland** intends to become the world's first hydrogen economy, with hydrogen produced from renewable electricity sources (geothermal and hydroelectricity).

Issues

Visions and scenarios

There is an emerging consensus that hydrogen could have a key role in energy systems. The Government's *Powering Future Vehicles* strategy states that *"the ultimate low-carbon destination looks likely to be fuel cells using renewably produced hydrogen"*. A hydrogen economy would include generation of hydrogen from diverse and distributed sources, used to power transport, homes and industry. Generation would be possible at a range of scales, from large centralised plants using technologies such as steam reforming, to forecourt or even domestic electrolysis and reforming units. Hydrogen could be distributed from the larger sites by road, pipeline, or sold in solid storage units.

The large number of possible production routes gives several benefits. Numerous organisations and even individuals could become producers of hydrogen, forming a new and diverse economy. The security of supply of transport fuel would be enhanced, especially if hydrogen were produced from UK renewable electricity, biomass, waste or gas supplies.

Hydrogen safety

If a hydrogen vehicle were involved in a collision in an **open space**, there would be less risk than with a petrol vehicle. This is because hydrogen is very light, and so any leak would dissipate rapidly into the air, reducing the risk of fire or explosion. Hydrogen is not toxic, so a leak would not cause environmental damage. In addition to this, hydrogen storage tanks are significantly tougher than petrol tanks, and so are less likely to cause a large leak.

In a **confined space**, hydrogen could lead to fire or explosion if mixed with air. Any fire started would burn out quickly as the hydrogen dissipated. Some studies have suggested that hydrogen vehicles would have lower risks than petrol vehicles in confined spaces as petrol leaks would create a larger cloud of flammable gas. Hydrogen burns with little radiation of heat, so nothing would burn unless it were immediately next to the flame. Sensors would be needed to detect any slow leakage of hydrogen, e.g. in a garage, as hydrogen is a colourless, odourless gas.

Conditions for transition

A transition to a hydrogen economy is uncertain, and not inevitable. Transitions have been investigated using scenarios for future energy systems. Some scenario exercises, such as those prepared for the PIU Energy Review, assumed that use of hydrogen would require large scale infrastructure development. It was not clear how this would be developed, given that many national infrastructures were developed by monopolies or public bodies. This uncertainty resulted in infrastructure development being considered to be the primary barrier to use of hydrogen, and so widespread use projected only for the long term, after 2050.

However, several other studies (e.g. the Foresight *Fuelling the Future* exercise) consider that such a wholesale infrastructure change is not necessary. It is argued that development could start from niche markets and 'islands' of hydrogen availability and so would not, for example, involve switching all filling stations to hydrogen at the same time. Providing hydrogen at a local fleet vehicle depot or as part of CHP schemes could expand to supplying vehicles in a local area. Once several schemes had built up, networks could be formed.

A UK development path

Despite these differences of view, it is widely thought that hydrogen use in the UK may begin with transport, in particular for fuelling fleet vehicles and buses. Buses have fixed routes and can be refuelled and maintained at depots. Using hydrogen in stationary applications such as small CHP schemes is thought likely to develop at the same time, although there is some uncertainty as to the level of contribution in the next decade.

The next step would then expand transport use of hydrogen to cars and other light vehicles. The use of hybrid vehicles, which have a battery as well as a fuel cell or conventional engine may act as a stepping-stone to fuel cell commercialisation, as expertise and standardisation of components develops. Hybrid vehicles give a significant efficiency improvement over current technologies.

Strategic approach

Benefits of a hydrogen economy, and barriers to its development, cut across policy on energy, transport, air pollution, planning, agriculture and waste. Proponents of hydrogen (e.g. IPPR and the Carbon Trust[3]) have argued for a high-level long term strategic approach to developing a hydrogen economy, identifying key challenges, setting target dates for development and deployment, and coordinating UK and EU projects and targets. This has begun with the Greater London Authority's launch of the London Hydrogen Partnership in 2002, which will develop a plan for use of hydrogen in the city and may provide experience for a national plan.

Incentives

Transition to a hydrogen economy could be promoted using targets, regulations, standards, planning guidance, fiscal measures, grants and public procurement.

Targets for emissions reduction promote environmental improvement without being technology specific. *Powering Future Vehicles* calls for 600 new 'low-carbon' buses per year by 2012. The EST considers, however, that long term emissions targets will not be met unless hydrogen in particular is actively supported now; it recommends that Government should work with bus and fuel companies, so that by 2010, 5-10% of new buses use hydrogen fuel cells (about 150-300 buses). *Powering Future Vehicles* also sets out intentions for longer term targets for new vehicles to meet 'ultra-low' carbon standards. However, the term 'ultra-low' has not yet been defined and so it is unclear whether this will promote hydrogen technologies.

Other approaches include:
- enabling local authorities to adopt mandates requiring zero emissions from a proportion of their bus fleet, enabling them to meet local air quality objectives
- harmonisation of UK standards for storage and use of hydrogen with international standards being developed
- support for hydrogen infrastructure development through planning guidance (e.g. the ODPM's current revision of renewable energy planning)
- electricity market systems to allow generators to produce electricity for hydrogen production, grid export and local distributed generation
- widening of agricultural support schemes to include hydrogen production from biomass energy crops.

Fiscal incentives can also be used. It has been proposed that zero fuel excise duty on hydrogen would promote the early stages of market development and would reflect the lower environmental impacts of hydrogen use. Under the Government's *Green Fuel Challenge*, no fuel duty will be levied on a pilot project using hydrogen in fuel cell buses. Subject to the outcome of this project, the Government intends to exempt hydrogen from duty for a limited period to encourage development and early take-up. As hydrogen use expands, variable fuel excise duty could be used to differentiate between hydrogen derived from different sources depending on its environmental impact. Inclusion of hydrogen production in the Climate Change Levy could also achieve this aim.

Other fiscal incentives could include:
- variable vehicle excise duty (VED) for cars with very low emissions, or zero VED for zero emission vehicles
- variable company car tax for low emission vehicles.

Use of hydrogen in fleet vehicles could be promoted by use in public authority vehicles and schemes to support companies converting a proportion of their fleet, potentially with removal of night time delivery bans in urban areas for quiet vehicles. It has also been suggested that direct grants should be made available to support infrastructure changes. In the private vehicle market, uptake of new vehicles could be supported by direct grants, such as those administered under the *Powershift* programme for gas, hybrid and electric vehicles.

Technological development

The Engineering and Physical Sciences Research Council has funded the UK hydrogen energy network, to promote hydrogen research. Beyond a network, some have called for a dedicated programme to coordinate and fund UK research efforts and support demonstration projects as in the US, Germany and Japan. The programme could also include feasibility studies to identify the potential role for hydrogen in different sectors and areas and manage UK participation in EU and international projects.

Public acceptance

Public awareness of the benefits of using hydrogen and provision of information on hydrogen safety are likely to be key to acceptance of the technology. Demonstration projects involving hydrogen use in buses and public buildings have been well accepted elsewhere in the world and are considered to be one of the best ways to introduce the technology to a wide range of people.

Overview

Hydrogen is widely considered to have a strong potential for use in future energy systems, meeting climate change, air quality, noise and resource use goals. Hydrogen technology is well established in industry and further commercialisation for vehicles and stationary uses is expected in the next few years. However, the need for cost reduction, demonstration, and infrastructure development mean that mass markets are unlikely before 2015. Nevertheless, many have called for coordinated research and demonstration now and a clear strategy to enable future infrastructure and market development.

Endnotes

1 The Energy Saving Trust is a non-profit organisation aiming to reduce CO_2 emissions, funded by Government and the private sector
2 Hybrid vehicles (e.g. diesel/battery) can also reduce CO_2 emissions
3 The Institute for Public Policy Research (IPPR) is a UK think tank. The Carbon Trust is an independent non-profit company set up by the Government to take the lead on low carbon innovation in the UK

POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of public policy issues that have a basis in science and technology. POST is grateful to Jo Howes and Imperial College for Energy Policy and Technology for the research undertaken in the preparation of this briefing note. A longer report is available on the POST website.

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www.parliament.uk/post/home.htm

Appendix 7

Topics to cover under tender

Understand the public's perceptions of hydrogen with reference to:

- Associations to hydrogen
- Awareness of hydrogen as an energy vector
- Awareness of hydrogen as a fuel
- Investigation into public's knowledge of hydrogen safety.

Determine acceptability of hydrogen technology with specific reference to

- Safety
- Environmental impact
- Security of supply
- Production methods (which would be most acceptable)
  - Fossil fuel
  - Renewable
  - Biological
- Distribution
- End uses

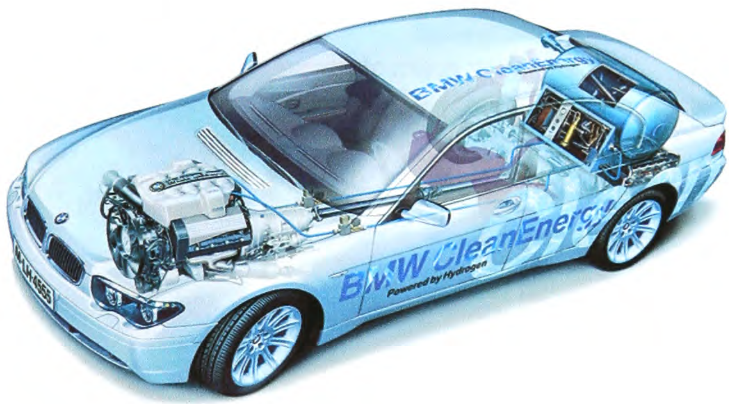
Additional areas needing to be investigated:

- General attitudes to environmental issues.

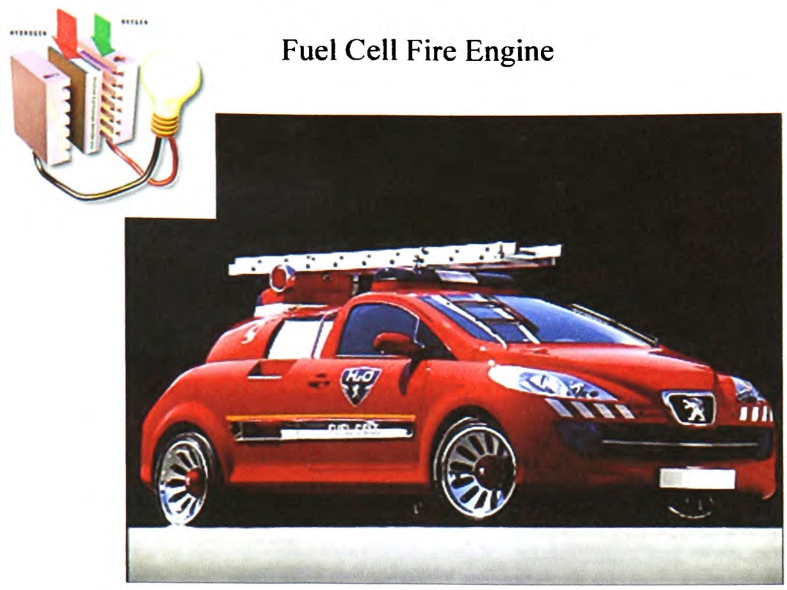
Appendix 8 – Photographs used in second session

Hydrogen fire after 90 seconds   Petrol fire after 90 seconds

Hydrogen Internal Combustion Engine BMW



Fuel Cell Fire Engine



Hydrogen can be made many ways

Fuel Cells come in all sizes

Pinetree Power Plant, Fitchburg, MA
Source: www.neonrg.org

Appendix 9 - Questionnaire

List of questions used to ascertain levels of acceptance to science and technology.

- I am not interested in science and I don't see why I should be?
- Because of science engineering and technology there will more opportunities for the next generation
- When I buy something like a washing machine, value for money is the MOST important thing I consider
- Science and technology are making our lives healthier, easier and more comfortable
- In general scientists want to make life better for the average person
- It is important to know about science in my daily life
- The more I know about science the more worried I am
- It is important to look after the environment
- I cannot follow developments in science and technology because the speed of developments is too fast
- Science is getting out of control and there is nothing we can do to stop it
- The speed of development in science and technology means that it cannot be properly controlled by the Government
- People make too much of environmental concerns